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SPECIAL NOTICE

Binding Cases and Indexes for Volumes 155, 156 and 157 (the twelve issues for 1947) are now ready. They will be despatched, in the next few weeks, to those who have already made a request to the Secretary.

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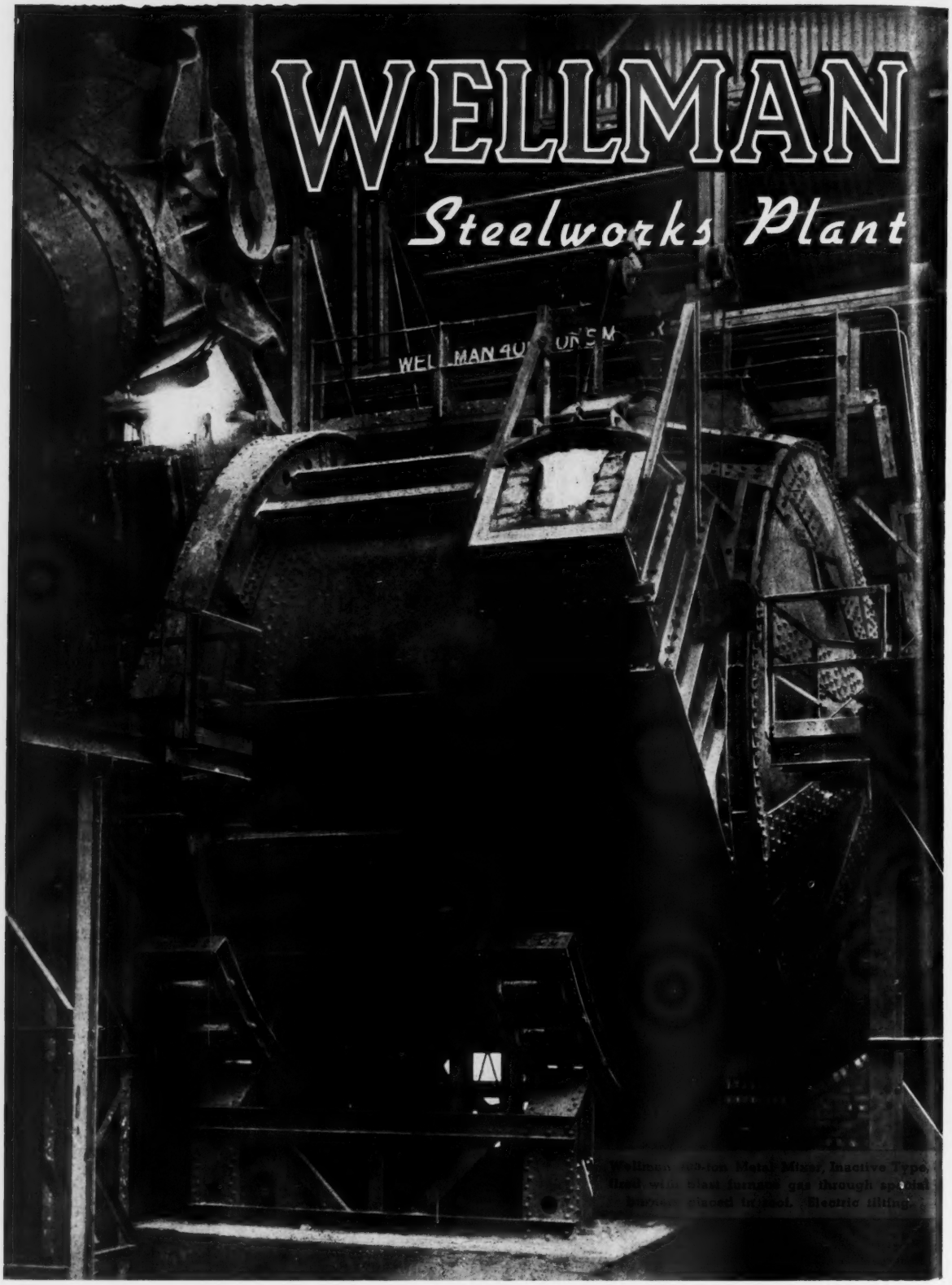

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JOHN WATSON JENKIN, Ph.D., A.R.I.C., F.I.M.

DR. J. W. JENKIN, Director of Research, Tube Investments, Ltd., Birmingham, was born at St. Austell, Cornwall, in 1899, and educated at St. Austell County School, at King's College, University of London, and at the University of Sheffield.

Dr. Jenkin served with H.M. Forces from 1917 to 1919, and was with the Metallurgy Department, National Physical Laboratory, during the years 1923-29 before being appointed to his present position. He was adviser on steel tubes to the Ministry of Supply from 1945 to 1946.

He is a Founder Fellow of the Institution of Metallurgists ; he was a Member of its first Council during the years 1945-46, and was elected President in 1946. A Member of Council of the British Iron and Steel Research Association, Dr. Jenkin also serves on the Metallurgy Divisional Panel, the Alloy Steels Research Committee, the Corrosion Committee, the Sub-Committee on Corrosion by Industrial Waters, of which he is Chairman, and the Sub-Committee on Soil Corrosion. He is a Member of Council of the British Welding Research Association and a member of the Institute of Fuel, the Electrodepositors' Technical Society, the American Institution of Mining and Metallurgical Engineers, and the American Society for Metals. In addition, he is a member of the following : the Joint Committee on National Certificates in Metallurgy ; the City and Guilds of London Institute's Advisory and Moderating Committees in Metallurgy ; the City of Birmingham Education Committee on Metallurgy ; the British Electrical and Allied Industries Research Association's Committee on Steels for High Temperatures and Pressures ; and various committees of the British Standards Institution.

He joined the Institute of Metals in 1922 and was Honorary Secretary of the Birmingham Local Section from 1932 to 1938, and Chairman from 1939 to 1940.

Dr. Jenkin became a Member of The Iron and Steel Institute in 1932 and was elected a Member of Council in 1946.

Elliot and Fry

Dr. J. W. Jenkin, Ph.D., A.R.I.C., F.I.M.
Member of Council

IRON AND STEEL
INSTITUTE PAPERS

PLANT DESIGN · MANUFACTURE · RESEARCH · DEVELOPMENT

The Formation of Sigma Phase in Duplex Chromium–Nickel–Molybdenum Corrosion-Resisting Steels

By H. W. Kirkby, A.Met., F.I.M., and J. I. Morley, A.Met., A.I.M.

SYNOPSIS

The results of an investigation of sigma formation in two 18/8 steels containing molybdenum and titanium in the one case and molybdenum and columbium in the other, are described. Time-temperature studies showed that sigma forms very rapidly at 850° C. in both these alloys with accompanying increase in hardness, loss of magnetism, and decrease in ductility. The results also suggest that the formation of sigma causes an alloy depletion locally, which may have an effect on corrosion resistance in certain circumstances.

A detailed study was made in regard to changes in microstructure accompanying sigma formation, using etching reagents designed to distinguish sigma from ferrite, austenite, and carbide.

THE investigations described originated as a result of occasional difficulties encountered in the large-scale manufacture of certain acid- and heat-resisting steels over a period of years. These steels were both 18/8 types with 3% of molybdenum, one being stabilized with titanium and the other with columbium. The former was produced mainly in the form of rolled plate of the order of $\frac{3}{8}$ in. thick, and over, whereas the latter was confined to applications requiring the material in the form of castings. Metallurgically, however, both materials behaved similarly in regard to the formation of sigma, so that only the titanium-bearing steel has been dealt with in any detail. Emphasis is laid on the metallurgical aspect of the subject in an attempt to correlate the microstructure with certain other properties.

Both the compositions investigated belong to the duplex ferrite–austenite class of alloy, and in such steels it is already established[1] that the sigma phase forms directly from the ferrite phase in a certain range of temperature, and the present paper confirms this. No attempt is made to review the literature fully, as a fairly up-to-date review of the subject has been prepared by Foley.[2] In view of this it is felt that only the published work relevant to the present paper need be discussed.

For the detection of the sigma phase, X-ray diffraction has been widely used in the past owing to the greater certainty associated with this method. Certain etching techniques have been claimed, however, to distinguish it from other constituents, principally carbide and ferrite.[3] In the present paper, reliance has been placed on X-ray methods to confirm the presence or absence of sigma phase, parallel microstudies being made using a newly developed etching reagent.

EXPERIMENTAL WORK

The analysis of the nickel–chromium–molybdenum–titanium steel used was as follows :

C, %	Si, %	Mn, %	Cr, %	Ni, %	Mo, %	Ti, %
0·07	0·80	0·63	18·00	8·52	3·22	0·67

Difficulties with this type of alloy were encountered during shearing and bending processes involving $\frac{1}{2}$-in. thick plate material in the nominal air-cooled 1050° C. condition. The material was found to have substantially reduced ductility, fracturing fairly readily with a rather laminated fracture. Preliminary examination revealed a number of abnormal features, among which were the following :

(*a*) Failure to respond to a hand magnet—this material is normally somewhat responsive to a magnet, since it possesses a mixed austenite–ferrite structure.

(*b*) Abnormal microstructure (*see* Fig. 10, *cf.* with Fig. 14 for normal structure).

(*c*) Relatively high Brinell hardness—260 as against the usual 200.

Retreatment of samples cut from the plates by air-cooling at 1050° C. in the laboratory restored

Manuscript received 10th December, 1947.

Mr. Kirkby and Mr. Morley are metallurgists at the Brown-Firth Research Laboratory, Sheffield.

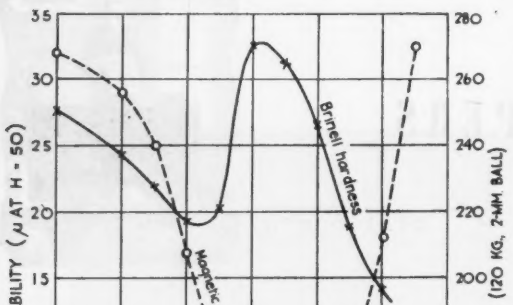

Fig. 1—Effect of reheating temperature on Brinell hardness and magnetic permeability

them to what was hitherto regarded as the normal condition, that is, highly ductile, partially magnetic, and possessing a structure typified by Fig. 14. The hardness was also reduced from approximately 260 to about 200 Brinell.

As a result of this, the commercial heat-treatment cycle was suspected and investigated. It was found that whilst the plates had attained a temperature of 1050° C. and had been soaked sufficiently, the rate of cooling attainable under the particular bulk-production conditions was insufficient to avoid the embrittled condition found earlier. This was confirmed by reproducing as closely as possible a similar heat-treatment cycle under laboratory conditions. Thus, " good " material, given this simulated cycle, appeared to possess all the properties of the commercially heat-treated low-ductility material.

Parallel X-ray studies on typical samples revealed that the reduction in ductility was associated with the presence of sigma phase in fairly substantial quantities.

EFFECT OF 1-HR. EXPOSURES AT 500–1000° C.

Mechanical and Magnetic Properties

It was decided to explore the changes in structure and properties in more detail, this work being carried out on both 10-gauge sheet material and $\frac{3}{4}$-in. dia. rolled bar.

As the preliminary work had indicated that the embrittlement and other effects encountered were related to some temperature or range of temperature below 1050° C., it was decided to explore this in the first place by reheating material (which had been previously water-quenched from 1050° C.) to various temperatures, using a soaking time of 1 hr. at each temperature. The range investigated was 500–1000° C. inclusive at intervals of 50° C. with final water-quenching in each case.

Figures 1 and 2 summarize the data obtained in regard to the effect of these reheatings on hardness, magnetic response, and ductility. It will be seen that the steel became considerably less magnetic and developed a peak hardness in the range 800–850° C. with a soaking time of 1 hr., suggesting some temperature in this range as the maximum for rate of sigma formation (Fig. 1). The corresponding reduction in ductility indicated by a fall in the results of bend tests to fracture from a 180° bend after quickly cooling from 1050° C. to a 50° bend after further treatment at 850° C. for 1 hr., is equally striking (Fig. 2). One-hour treatments at temperatures higher or lower than 850° C. produced progressively smaller effects, until 1 hr. at 1000° C. or 1 hr. at 500° C. gave little change from the results of tests in the original quickly cooled condition. Had treatments of more than 1 hr. at the various temperatures been employed it is probable that the susceptible range of temperature would have widened, though perhaps not to any considerable extent. The relatively high hardness at 500° C., which seems to be in the nature of a subsidiary peak, is considered to be due to a precipitation of titanium carbide, and appears to be independent of the main effect with which this paper is concerned.

Microstructure

After quenching from 1050° C., the alloy possesses a mixed ferrite–austenite microstructure with about equal proportions of the two phases, as illustrated in Figs. 14 and 15. Without much experience it is a difficult matter visually to decide which phase is the ferrite and which is the austenite, so that as a preliminary it is useful to employ a technique which differentiates readily between those phases. A procedure has been described[4] based on the ferromagnetism of the ferrite phase and the use of a colloid-pattern technique which gives a positive identification of the ferrite areas. In this method the application of a magnetic field to a specimen coated with a thin colloidal suspension of iron particles causes a concentration of colloid over the magnetic phase which simplifies considerably identification of the ferrite.

With increased experience it is not always necessary to apply this technique since ordinary etchants (*e.g.*, 20% hydrochloric acid) do have slightly different etching effects on the ferrite and austenite.

In the reheating series to be described, however, the changes observed did not need special technique from the point of view of distinguishing ferrite from austenite, because of the magnetic changes already

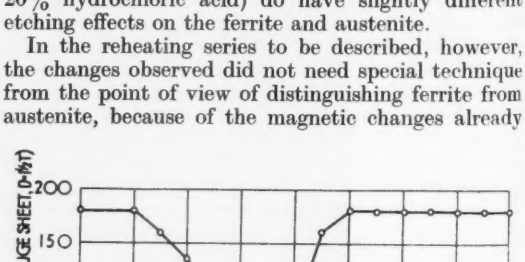

Fig. 2—Effect of reheating temperature on ductility

described. It was obvious, therefore, that the ferrite phase was affected by the reheatings.

Figures 4 to 15 trace the changes in microstructure which occurred during 1-hr. reheatings in the range 500–1000° C. The photomicrographs, all of which are at 1500 diameters, are arranged in pairs to show the effect of different etching reagents on each specimen. The two reagents were (1) 10% oxalic acid and (2) a potassium-iodide/citric-acid solution,* both being used electrolytically with the specimen as anode. The nature of the chemical attack differs with the two reagents: oxalic acid first outlines and, on longer etching, actively dissolves the sigma grains from the surface; the iodide reagent leaves the sigma in relief and in some cases produces marked pitting of adjacent areas on the specimen. As the oxalic acid reagent does not attack ferrite it usefully distinguishes between the sigma and ferrite, whilst the localized attack of the other reagent during the formation of sigma seems to indicate changes in solid-solution concentration associated with the transformation.

In the structure revealed by oxalic acid the distribution of the sigma is indicated by deep non-reflecting pits which become fewer and coarser as the temperature of heat-treatment is increased. Exposure for 1 hr. at 500° C. produces no detectable change by micro, X-ray, or magnetic methods. A fine precipitation occurs in the ferrite at 600° and at 650° C., the effect resembling a " troostitic " etch at lower magnifications (Figs. 5 to 7). Whilst both reagents attack the ferrite after the 650° C. treatment, the 600° C. treatment gives the effect only with the iodide reagent. Treatment at 750° C. resulted in structures comparable with those of the specimens treated at 850° C., but on a finer scale.

The microstructural features produced by 1 hr. at 850° C. are sufficiently gross to permit recognition of three distinct phases in the lately ferritic zones. Etching in oxalic acid, as in Fig. 10, suggests that the original ferrite network has partly broken down at the end of 1 hr. into two constituents. One of these, apparently corresponding with the sigma phase, is deeply pitted; the other, an interstitial phase, is not so susceptible to attack in the oxalic acid reagent. In addition, what appear to be fragments of the original ferrite grains still unchanged in etching behaviour after an exposure of 1 hr. are visible in the same photomicrograph as sharply outlined highly reflecting pools, often in the centre of the zones of active transformation. As previously mentioned these constituents react differently to the iodide reagent. Figure 11, representing the same specimen with an iodide etch, shows the sigma in relief owing to deep etching of the interstitial zones and attack on the ferrite residues at the grain centres.

Similar but grosser effects were noted after 1 hr. at 900° C. Exposure for 1 hr. at 950° C. produced relatively massive sigma in certain parts of the ferrite network, the remainder being only slightly attacked by the iodide reagent (Figs. 12 and 13), sufficient almost to eliminate the contrast between

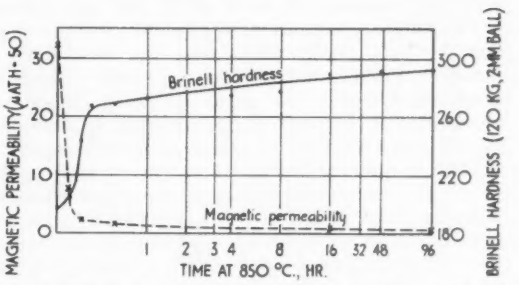

Fig. 3—Effect of time of exposure at 850° C. on Brinell hardness and magnetic permeability

ferrite and austenite in the etched structure. The ferrite–austenite boundaries, however, are still visible, though somewhat distorted from their original smooth outlines. Treatment at 1000° C. for 1 hr. gave no noticeable change from the original 1050° C. quenched structure (Figs. 14 and 15).

EFFECT OF EXPOSURES OF MORE THAN 1 HR. AT 850° C.

Further study was made on the influence of time on the magnetic properties, hardness, and microstructures after reheating at 850° C., for various times, material water-quenched at 1050° C. The temperature of 850° C. was chosen since it appeared to be in the region of a " peak " effect due to sigma formation.

Figure 3 summarizes the results of hardness and magnetic tests obtained, while Figs. 16–27 illustrate the microstructures observed in each case. It will be seen that the change in properties and formation of sigma phase is progressive at 850° C., commencing at very short times, certainly less than 5 min., and being substantially complete after 2 hr., when the steel becomes apparently non-magnetic. With treatments of more than 2 hr., slightly higher hardness values were obtained.

The microstructures show that breakdown commences at the margins of the ferrite grains, gradually extending until, after 30 min. at 850° C., only small pools of the ferrite remain (Fig. 22). After 2 hr., the ferrite seemed to have completely disappeared from the microstructure, and corresponded with loss of magnetism. Figure 24 shows the structure after 4 hr. to consist of austenite and sigma.

As previously explained, ferrite and sigma are not distinguished from each other by the iodide etching. The interesting feature of this etch is the localized attack on the ferrite or lately ferritic zones in the vicinity of the sigma particles (Figs. 19, 21, and 23).

Similar pitting produced by this etch in the neighbourhood of the brittle phase after exposure for 4 hr. (Fig. 25) occurs in what appear to be austenitic zones as this specimen was completely non-magnetic. Comparing this structure with that of the original condition water-quenched from 1050° C. (Fig. 17), it will readily be seen that the austenitic regions susceptible to the iodide reagent after 4 hr. at 850° C. were formerly parts of the ferrite network. Figures 28 and 29, at lower magnifications and showing the effect of 16 hr. at 850° C., also illustrate the apparent smaller total volume of the sigma particles compared

* 450 g. of citric acid, 300 g. of potassium iodide, 60 g. concentrated hydrochloric acid, made up to 900 c.c. with water.

with the ferrite grains from which they are formed.

The inference appears to be twofold : (1) that sigma and austenite finally result from the breakdown of ferrite at 850° C., and (2) that the " new " austenite produced alongside the grains of sigma phase may be of different composition from the original austenite, as it is more sensitive to attack in iodide reagent.

With treatments of more than 4 hr. at 850° C., this local difference in etching behaviour of the austenite disappears. A period of 8 hr. is evidently sufficient to equalize the rate of attack, and the etched structure then resembles that of Fig. 27. Between 8 and 96 hr. at 850° C. no structural changes were detected, apart from a further slight spheroidization of the sigma constituent.

Reviewing the observed effects associated with treatment at 850° C., the formation of sigma appears to spread in an advancing wave across the ferrite grains, commencing at the grain boundaries. As the sigma forms from the ferrite, there appear also to be changes in the residue ferrite since it is attacked readily by the iodide reagent and also by certain other reagents which normally do not affect the ferrite. This suggests the possibility of a local depletion of alloys in what was originally the residue ferrite as the result of diffusion into the newly formed and growing sigma particles. Eventually this constituent may be identified as austenite by the loss of magnetism after 2- or 4-hr. treatments and by the absence of any sharply defined boundary between it and the original austenite.

RESIDUE ANALYSIS

To obtain further evidence of alloy enrichment in the sigma phase and consequently local impoverishment, an attempt was made to extract the sigma phase for subsequent analytical purposes. Two reagents were used, both electrolytically, namely, (1) potassium-iodide/citric-acid solution, and (2) 50% hydrochloric acid. Analyses were carried out on residues obtained with the first reagent on one sample treated by water-quenching at 1050° C. and on a second sample which was given an additional treatment at 850° C. in order to convert the ferrite to sigma. The results of the analyses were as follows :

Extraction No. and Condition	Analysis*				
	Cr, %	Ni, %	Mo, %	Ti, %	Fe, %
1, *A* ...	0·58	0·25	0·20	0·12	2·0
2, *A* ...	1·15	0·42	0·30	0·21	3·48
1, *B* ...	4·43	0·60	1·40	0·36	8·35
2, *B* ...	3·50	0·44	1·14	0·33	5·70

A = 1050° C., W.Q.
B = 1050° C., W.Q. + 16 hr. at 850° C.

* *N.B.*—Expressed as percentages of the original weight of steel dissolved.

These results suggest that a general enrichment of alloy in the residue has occurred, but it was suspected that some undissolved steel was present. (Tentative corrections based on the assumption that the recovered nickel was largely due to undissolved steel indicated that the residue of the specimen treated at 850° C. was enriched in chromium, iron, and molybdenum.) An appreciable residue, in fact more than was expected, was obtained from the specimen water-quenched from 1050° C., and further reference will be made to this in the next section, dealing with X-ray examination of the residues.

X-RAY EXAMINATION

The results of X-ray diffraction studies on the steel specimens treated at 850° C. indicated weak sigma lines after 1-hr. treatment and that soaking times of more than 4 hr. at this temperature do not increase the amount of sigma appreciably. One hour at 850° C. was sufficient to remove all evidence of ferrite from the X-ray spectra.

Residues prepared in a manner similar to that described in the previous section were also examined. The strongest sigma patterns were obtained from the residues of the potassium-iodide/citric-acid attack on specimens treated at 850° C. The residue from the same reagent after water-quenching from 1050° C. gave strong alpha reflections only, and the residue turned out to be almost entirely magnetic. This result suggested that some ferrite had been extracted from austenite in the 1050° C. treated specimen by using the iodide reagent. The selective attack on austenite in these specimens was confirmed by micro-examination after 3-min. etching periods as shown in Figs. 28 to 30. It is of particular interest that after the 1050° C. treatment followed by rapid cooling, the ferrite component is not readily attacked, whilst the austenite is. This behaviour suggests a difference in composition between the two phases and, judging by the immunity of sigma to this reagent (Fig. 29), an enrichment in chromium and molybdenum in the ferrite may be responsible.

In this connection it should be emphasized that the photomicrographs reproduced in Figs. 28 to 32 were obtained by relatively prolonged etching in the iodide reagent. Local differences in rate of attack associated with the incidence of sigma, such as those described in an earlier section, were apparent before the heavy relief effects indicated by these photographs were obtained.

As a check on the suspected difference in composition between the ferrite and austenite phases in the high-temperature-quenched alloy, some micro-radiographic work was carried out on specimens water-quenched at 1050° C. and 1150° C. The radiographs are reproduced in Figs. 34 to 40, along with photomicrographs of the same specimens, all at 100 diameters.

Thin specimens about 0·002 in. thick were prepared in the direction of rolling from bars, and radiographed on maximum-resolution film. Using iron and chromium characteristic X-radiations, different effects were produced. Iron radiation revealed a banded structure (Figs. 34 and 36), the heaviest absorptions in which corresponded closely with the ferrite areas viewed on the same section under the microscope at 100 diameters. On the other hand, chromium radiation revealed only the lines of titanium carbide inclusions (Fig. 38). The known heavy absorption of iron radiation by chromium segregates and the relatively much smaller absorption of chromium radiation were the basis of these tests, which clearly indicated that the ferrite component was richer in chromium than was the austenite.

Treatments at 850° C. for 16 hr. increased the contrast in the micro-radiographs considerably (Fig. 39), consistent with the concentration of chromium in the original ferrite areas due to the separation of

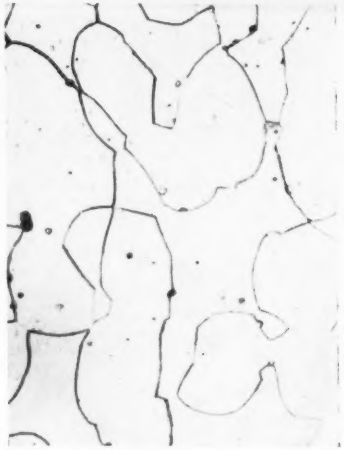

Fig. 4—600° C., oxalic etch

Fig. 5—600° C., iodide etch

Fig. 6—650° C., oxalic etch

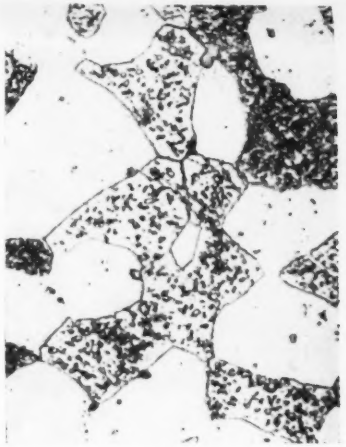

Fig. 7—650° C., iodide etch

Fig. 8—750° C., oxalic etch

Fig. 9—750° C., iodide etch

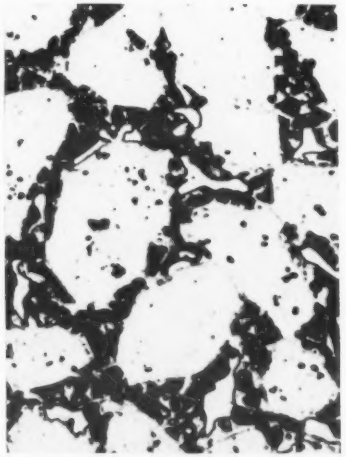

Fig. 10—850° C., oxalic etch

Fig. 11—850° C., iodide etch

Figs. 4 to 11—Effect of reheating for 1 hr. at temperatures in the range 600–1000° C.; Figs. 4, 6, 8, and 10 etched electrolytically in 10% oxalic acid; Figs. 5, 7, 9, and 11 etched electrolytically in a potassium-iodide/citric-acid solution × 1500

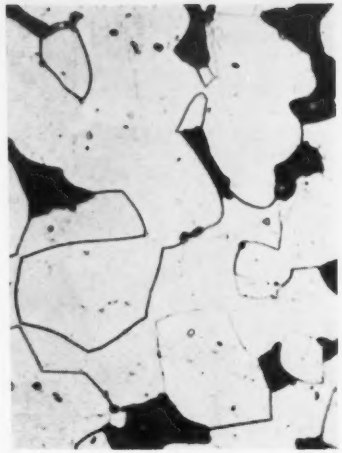

Fig. 12—950° C., oxalic etch

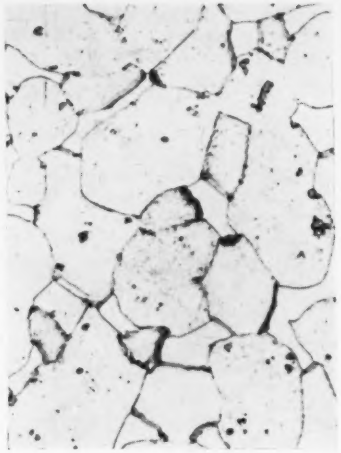

Fig. 13—950° C., iodide etch

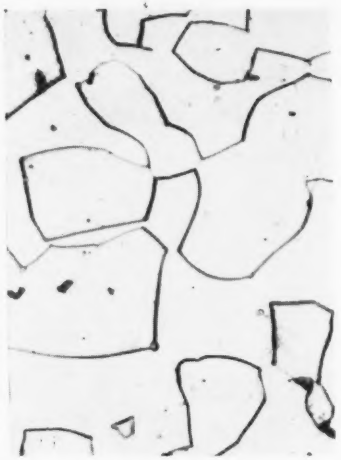

Fig. 14—1000° C., oxalic etch

Fig. 15—1000° C., iodide etch

Figs. 12 to 15—Effect of reheating for 1 hr. at temperatures in the range 600–1000° C.; Figs. 12 and 14 etched electrolytically in 10% oxalic acid; Figs. 13 and 15 etched electrolytically in a potassium-iodide/citric-acid solution × 1500

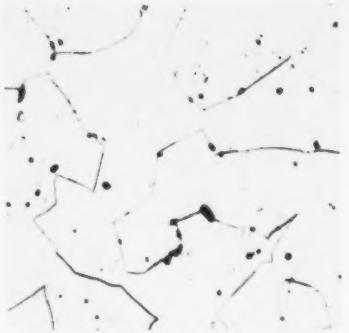

Fig. 16—W.Q. at 1050° C. only

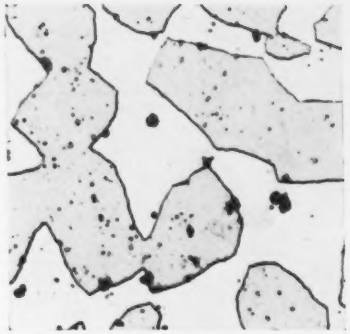

Fig. 17—W.Q. at 1050° C. only

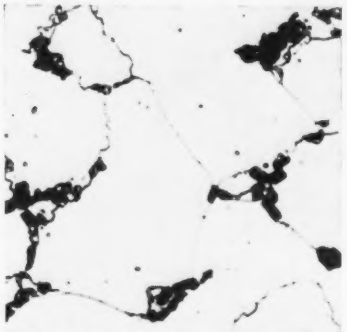

Fig. 18—1050° C. W.Q., 5 min. at 850° C.

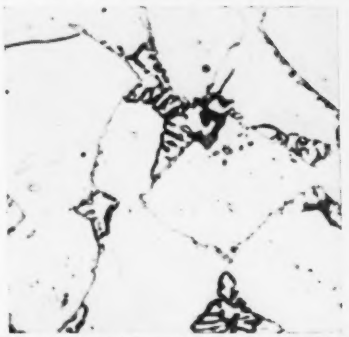

Fig. 19—1050° C. W.Q., 5 min. at 850° C.

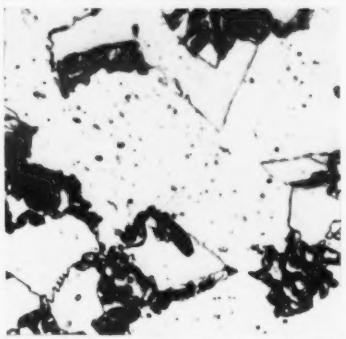

Fig. 20—1050° C. W.Q., 10 min. at 850° C.

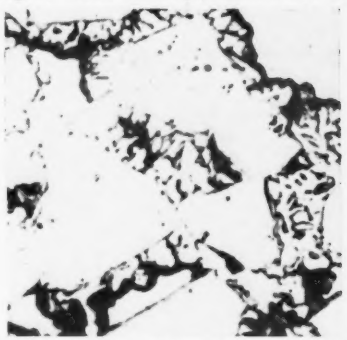

Fig. 21—1050° C. W.Q., 10 min. at 850° C.

Figs. 16 to 21—Effect of various exposures at 850° C. Figs. 16, 18, and 20 etched electrolytically in 10% oxalic acid; Figs. 17, 19, and 21 etched electrolytically in a potassium-iodide/citric-acid solution × 1500

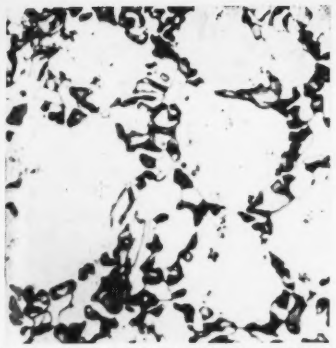

Fig. 22—1050° C. W.Q., 30 min. at 850° C.

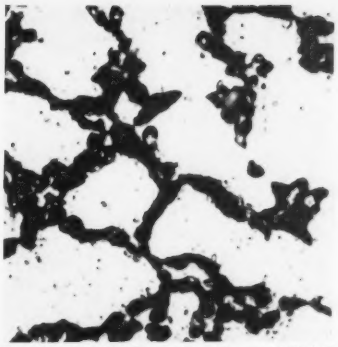

Fig. 24—1050° C. W.Q., 4 hr. at 850° C.

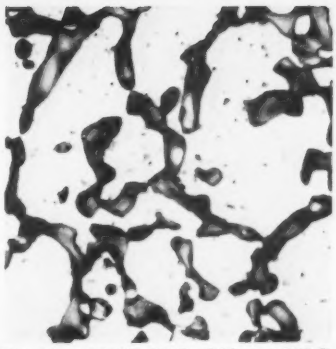

Fig. 26—1050° C. W.Q., 96 hr. at 850 C.

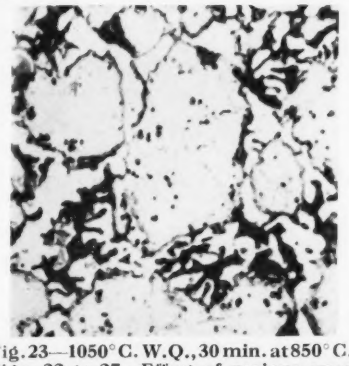

Fig. 23—1050° C. W.Q., 30 min. at 850° C.

Fig. 25—1050° C. W.Q., 4 hr. at 850° C.

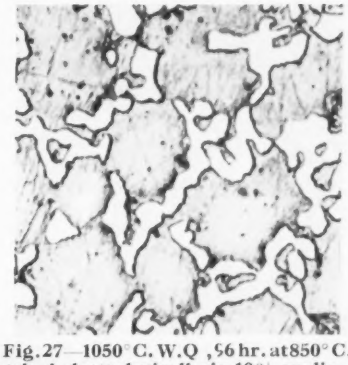

Fig. 27—1050° C. W.Q ,56 hr. at 850° C.

Figs. 22 to 27—Effect of various exposures at 850° C. Figs. 22, 24, and 26 etched electrolytically in 10% oxalic acid; Figs. 23, 25, and 27 etched electrolytically in a potassium-iodide/citric-acid solution × 1500

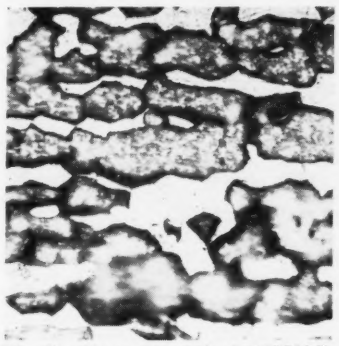

Fig. 28—Water-quenched at 1050° C. only. Longitudinal section. Deep iodide etch; austenite attacked, ferrite in relief

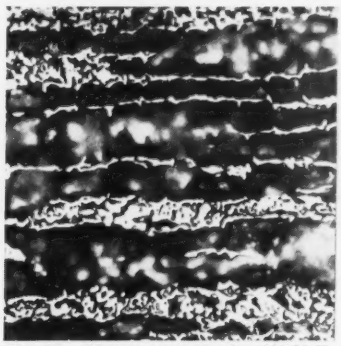

Fig. 29—Water-quenched at 1050° C. plus 16 hr. at 850° C. Longitudinal section. Deep iodide etch; austenite attacked, sigma in relief

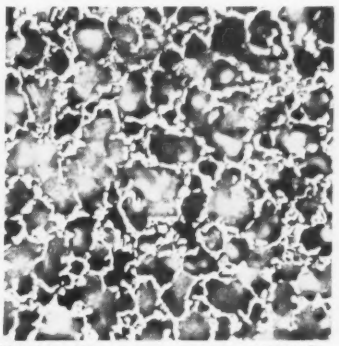

Fig. 30—Water-quenched at 1050° C. plus 16 hr. at 850° C. Transverse section. Deep iodide etch; austenite attacked, sigma in relief

Figs. 28 to 30—Structures before and after 16 hr. at 850° C. Deep-etched electrolytically in a potassium-iodide/citric-acid solution × 500

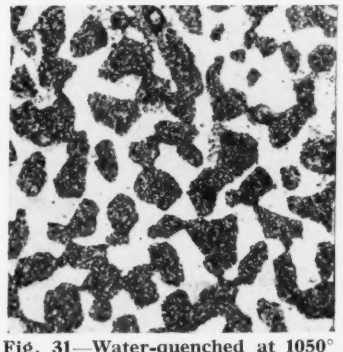

Fig. 31—Water-quenched at 1050° C. Deep iodide etch; austenite attacked, ferrite in relief × 500

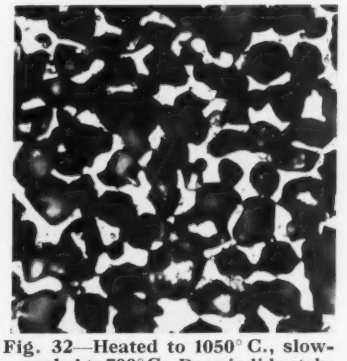

Fig. 32—Heated to 1050° C., slow-cooled to 700° C. Deep iodide etch; austenite attacked, sigma in relief × 500

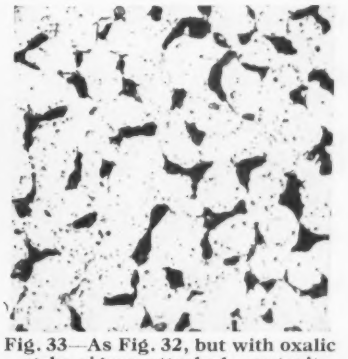

Fig. 33—As Fig. 32, but with oxalic etch; sigma attacked, austenite, white × 500

Figs. 31 to 33—Effect of slow-cooling treatment. Figs. 31 and 32 deep-etched electrolytically in a potassium-iodide/citric-acid solution; Fig. 33 etched electrolytically in 10% oxalic acid

[*Kirkby and Morley*

Figs. 16 to 21—Effect of various exposures at 850° C. Figs. 16, 18, and 20 etched electrolytically in 10% oxalic acid; Figs. 17, 19, and 21 etched electrolytically in a potassium-iodide/citric-acid solution × 1500

600–1000° C.; Figs. 12 and 14 etched electrolytically in 10% oxalic acid; Figs. 13 and 15 etched electrolytically in a potassium-iodide/citric-acid solution × 1500

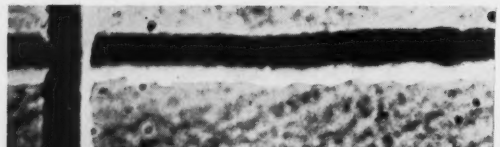

Fig. 34—Water-quenched at 1150° C. Micro-radiograph, Fe X radiation

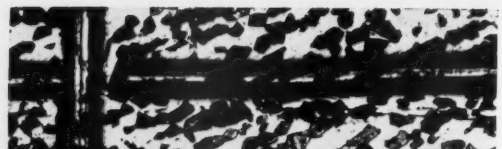

Fig. 35—Photomicrograph of same area as Fig. 34. Etched in potassium-iodide/citric-acid solution × 100

Fig. 36—Water-quenched at 1050° C. Micro-radiograph, Fe X radiation × 100

Fig. 37—Photomicrograph of same area as Fig. 36. Etched in potassium-iodide/citric acid solution × 100

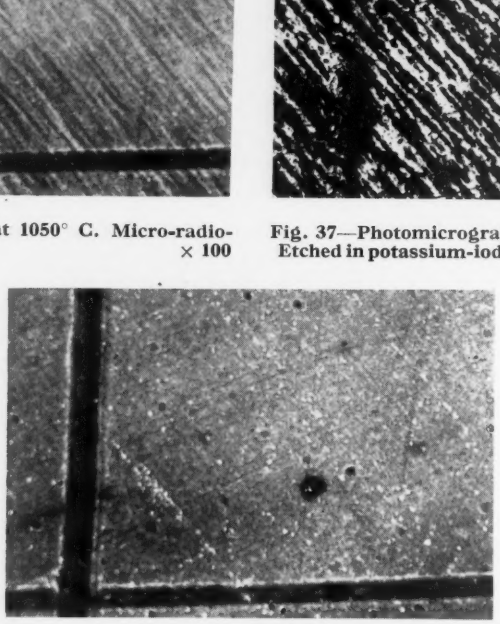

Fig. 38—Water-quenched at 1050° C. Micro-radiograph (same specimen), Cr X radiation × 100

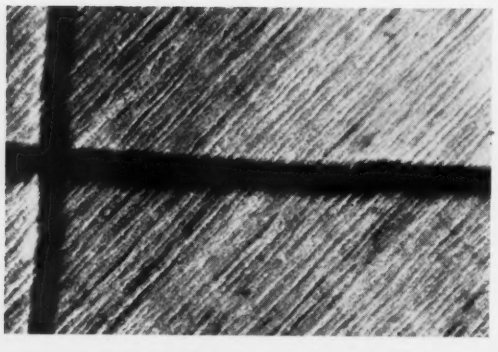

Fig. 39—Water-quenched at 1050° C. plus 16 hr. at 850° C. Micro-radiograph, Fe X radiation × 100

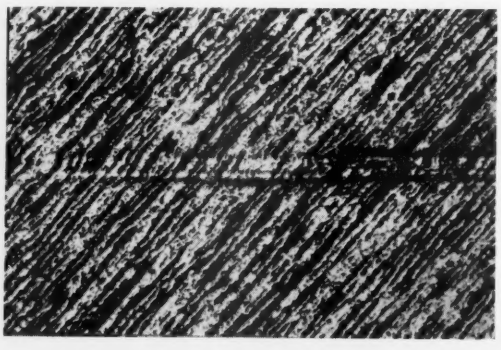

Fig. 40—Photomicrograph of same area as Fig. 39 × 100

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To face p. 293]

sigma phase. The micro-radiographic work on this and other alloys will form the subject of a separate paper to be published at a later date.

EFFECT OF SLOW COOLING FROM 1050° C.

The initial experiments confirmed that intermediate rates of cooling, as, for example, on the works-treated plates, resulted in ferrite breakdown and the characteristic mottled etch on ferritic zones.

A further experiment was undertaken to indicate the effect of very slow cooling rates. The specimen represented by Figs. 31 to 33 was cooled at 10° C./hr. from 1050° C. to 700° C. and quenched. The usual indications of sigma formation were provided by X-ray, hardness, and magnetic tests. In this case, however, the microstructural features were different from those obtained by reheating to 850° C. after quenching at 1050° C.

The sigma appeared massive, as shown in Figs. 32 and 33, suggesting that the austenite resulting from the breakdown had merged with the original austenite grains, leaving a core of the brittle constituent in place of each ferrite grain. The X-ray examination confirmed this apparent difference in grain-size between sigma obtained by very slow cooling and sigma obtained by quenching and reheating. As indicated by the photomicrograph (Fig. 33), no ferrite could be detected after this very slow cooling to 700° C., and the specimen was entirely non-magnetic. No change was detected after further reheating at 750° C., suggesting that the original very slow cooling had allowed a close approach to equilibrium conditions.

COLUMBIUM-STABILIZED STEELS

Considerable experience has been gained of columbium-stabilized chromium–nickel–molybdenum steel in the form of castings, of which the analyses are given below. Behaviour similar to that of the titanium-stabilized steels was observed, as is illustrated by the mechanical-test results :

	Cast 25113	Cast 25162
Carbon, %	0·13	0·13
Silicon, %	0·96	0·95
Manganese, %	0·99	0·95
Chromium, %	18·98	18·89
Nickel, %	8·45	8·45
Molybdenum, %	3·11	3·11
Columbium, %	1·05	0·98
Yield point, tons/sq. in. ...	18·2	27·2
Maximum stress, tons/sq. in.	36·8	43·2
Elongation, %	4	29·0
Reduction of area, % ...	2	25

Cast 25113 was virtually non-magnetic, whilst cast 25162 showed quite a marked response to a hand magnet. X-ray examination revealed the presence of sigma phase in cast 25113, but it was found to be virtually absent in cast 25162. Retreatment of small bend test-pieces ($\frac{1}{2} \times \frac{1}{16}$ in. $D = 2T$) restored ductility in cast 25113 :

Cast	Treatment	Angle of Bend
25113	1050° C. A.C. *	5°
25113	1050° C. W.Q.	170°
25162	1050° C. A.C. *	90°
25162	1050° C. W.Q.	180°

* Works heat-treatment in bulk

It was also shown that an 850° C. treatment after water-quenching from 1050° C. induced a similar degree of brittleness.

Cast	Treatment	Angle of Bend
25113	1050° C. W.Q. + 850° C. 1 hr.	15°
25162	,, ,, ,,	10°

Magnetic response was virtually nil in each case. The microstructural features closely resembled those of the titanium-bearing alloys.

DISCUSSION

The 18/8/3 titanium or columbium steels as quickly cooled from softening temperatures of about 1050° C. have the mixed ferrite–austenite structure characteristic of molybdenum-bearing 18/8 steels. Etching behaviour, micro-radiography, and the indications of chemical residue analysis provide reasonably good evidence that in this connection the ferrite component is richer in certain alloying elements, probably including chromium, than is the austenite. Contrary to published statements,[5] it does not seem possible, therefore, to indicate the lower limit of sigma formation in terms of chromium content in an alloy having a mixed austenite–ferrite structure, since the chromium content of the ferrite phase may well be above the nominal chromium content of the material in question. It would appear that such studies should be made on initially wholly austenitic alloys.

In the quenched condition, the type of alloy investigated is unstable and tends to revert to its equilibrium structure of austenite and sigma on further heating, sigma forming from the chromium-rich ferrite. Very slow cooling (10° C./hr.) evidently permits a fairly close approach to equilibrium as further heating below 850° C. is without effect. Cooling at intermediate rates may also result in sigma formation.

This work confirms earlier published work[1] that in such duplex austenite–ferrite alloys sigma forms very rapidly directly from the ferrite phase. The rate of formation at 850° C. is particularly rapid, detectable amounts being noted in the microstructure after only 5 min. at the temperature. The change to sigma in the steels examined is accompanied by loss of magnetism owing to progressive reduction in ferrite content. The Brinell hardness is increased and the ductility is also adversely affected by sigma formation.

The range of sigma formation appears to be fairly wide, sigma having been detected between temperature limits of 600–950° C. inclusive, on the basis of short reheatings. Both temperature and time of reheating appear to influence the state of division of the sigma phase, but it can be obtained in relatively massive form by very slow cooling from 1050° C.

Micro studies indicate that the ferrite phase transforms eventually to sigma phase and new austenite. During the process, however, the etching characteristics suggest that as the sigma forms, it gives rise to local alloy depletions, as a result of the sigma phase becoming enriched in alloys, particularly chromium. The subsequent recovery of resistance to certain etching reagents, obtained with the longer reheating times at 850° C., suggests the possibility of an equalizing diffusion of chromium and other elements

from the original austenite into the impoverished zones, as a sequel to the formation of sigma.

Franks, Binder, and Bishop[1] gave the results of numerous corrosion tests in various media on molybdenum-bearing chromium–nickel steels with and without columbium additions. Some of their steels resembled those used in the present investigation and in certain cases they found that prior treatment for 4 hr. at 650° C. considerably reduced the resistance to attack in boiling 65% nitric acid, compared with the annealed condition. On the other hand, at 870° C., the temperature at which sigma formation causes the greatest loss of toughness, a 4-hr. treatment gave a much smaller corrosion loss. It was suggested that the finer precipitates of sigma and carbides formed at 650° C. have a greater adverse effect on corrosion resistance than have the larger carbide and sigma-phase particles formed at 870° C. A somewhat different interpretation is possible in the light of the present work. If, as visualized, local alloy depletions resulting from sigma formation are responsible for a temporarily increased attack by the etchant, then it may be that in treating their specimens for 4 hr. at 870° C., Franks, Binder, and Bishop had in fact exceeded the time required at this temperature for the maximum corrosive effect. Yet after 4 hr. at 650° C. the steels were still in their most susceptible condition, suggesting that, owing to the slower rate of diffusion, 4 hr. at this temperature were insufficient to allow the alloy-depleted zones to equalize in composition with the original austenite. Thus the only satisfactory way in which the effect of individual reheatings at various temperatures on corrosion resistance could be compared, is on a differential time basis.

In attempts to interpret the corrosion behaviour of complex alloy steels of the type under consideration, it is of course necessary to allow for the effects of both carbide precipitation and sigma formation, as it may not always be possible to distinguish the two. The steels with which this work is concerned, however, were " stabilized " with titanium or columbium, so that the rôle of carbide precipitation may be considered relatively as a minor one. The localized etching effects produced by the special etching reagents used in this investigation indicate that the presence of the sigma constituent may modify the corrosion resistance.

On the other hand, a considerable tonnage of the molybdenum-bearing titanium-stabilized 18/8 austenitic steel is in service, and its behaviour has been such that designers of chemical plant regard it as one of their standard materials of the steels under onerous corroding conditions. Most of the plant constructed from this material has been welded, and has not been heat-treated after welding. Whilst, therefore, the significance of the features described in this paper should not be overlooked, the possible effects in service of the presence of sigma should be viewed in a proper perspective.

Acknowledgments

The authors are grateful for the assistance given by Mr. J. D. Lavender and Mr. J. E. Wells in connection with certain aspects of the work, and wish to thank Dr. C. Sykes, F.R.S., Director of Research, the Brown-Firth Research Laboratories, for permission to publish this paper.

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THE UNIVERSITY OF BIRMINGHAM
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Six scholarships of the annual value of £50, tenable for three years in the Department of Metallurgy, University of Birmingham, will be awarded in 1948. Conditions of the award of the scholarships are as follows :

(1) These scholarships are eligible for supplementation by the Ministry of Education. The Ministry is prepared to add a maintenance allowance in each case which will be based on a means test.

(2) Applicants must have complied with the requirements of the Joint Matriculation Board for entry upon a degree course.

(3) Applicants should possess the Higher School Certificate of a recognized examining body, or be candidates for such certificates in the year in which they are candidates for the scholarship.

(4) Alternatively, candidates may possess the Intermediate B.Sc. of the University of London, or be candidates for the examination in the year of the award of the scholarship.

(5) Candidates for the scholarship must present, or have presented, Chemistry, Physics, and Mathematics at the Higher School Certificate Examination or London Intermediate Examination, two at least of these subjects being at principal or group standard.

(6) A Metallurgy Scholarship cannot be held along with a State Scholarship or any similar award of comparable value, nor by a student in the Education Department under the regulations for the Training of Teachers.

(7) The continuance of the scholarship will be subject to satisfactory reports on the scholar's work and conduct.

(8) Scholars will be expected to begin their University course in October 1948.

(9) Applications for the scholarship should be forwarded to the Registrar of the University of Birmingham not later than *30th June, 1948*. (A form of application and a syllabus of the Faculty of Science can be obtained from the Registrar.)

(10) The scholarships are restricted to candidates of British nationality born not earlier than 1st January, 1923.

(11) Final acceptance of each candidate is subject to the approval of the Joint Recruiting Board.

The Occurrence and Some Effects of Sigma Phase in a Molybdenum-Bearing Chromium–Nickel Austenitic Steel

By L. Smith, B.Sc., A.I.M., and K. W. J. Bowen, B.Sc.

SYNOPSIS

The existence of a hard, brittle non-magnetic phase, analogous to the compound FeCr, and called the sigma phase, has been confirmed in 18/8/3/1 chromium–nickel–molybdenum–titanium steel. Microstructurally, the steel as water-quenched from 1150° C. consists principally of two phases—austenite and ferrite in approximately equal proportions. It is shown that when this steel is reheated in the temperature range 500–970° C. the sigma phase is formed from the ferrite. This paper describes the formation of the sigma phase and examines its effect on mechanical properties and corrosion resistance. It has been found that the presence of sigma in this steel increases hardness and appreciably decreases impact resistance, while the corrosion resistance of the steel to certain liquors is greatly reduced. The investigation has been aided by the development and use of an instrument, the Ferrometer, which enables changes in ferromagnetism in a steel to be followed and measured. X-ray crystallography has been used to throw light on the structure of the sigma phase, while microscopical examination of specimens of large grain-size has enabled an illustrated survey of the microstructure over the range of temperature 500–1150° C. to be made. In addition, the mode of formation of sigma from ferrite at 850° C., the temperature at which the percentage of ferrite in the steel decreases most rapidly, has been explored.

THE work described in this paper was initiated by the discovery that the corrosion resistance of 18/8/3/1 chromium–nickel–molybdenum–titanium steel in certain strongly corrosive liquors was adversely affected by heating in the region of 800° C. This type of steel is becoming increasingly used and it was considered essential that the reason for this phenomenon should be investigated.

Preliminary experiments showed that heating in the range 650–900° C. reduced the permeability of the steel and resulted in the formation of a hard constituent. It was suspected that this hard constituent was the sigma phase which has been mentioned in the literature.

DEVELOPMENT OF THE CHROMIUM-NICKEL AUSTENITIC STEELS

The chromium–nickel austenitic steels have been in general use in the chemical industry for some twenty-five years. The original steels contained only chromium and nickel as the alloying elements, the carbon content being about 0·16%. The actual chromium and nickel contents varied somewhat; for instance, there were 18/8, 15/11, and 12/12 chromium–nickel steels, but eventually the 18/8 type came into most general use.

In the condition in which 18/8 steel is normally supplied, namely, quickly cooled from about 1050° C., the structure of the steel consists of austenite. Heating the steel in the temperature range 500–900° C. causes the precipitation from this austenite of chromium carbide at the grain boundaries. The areas of austenite in the vicinity of these carbide particles will be impoverished in chromium and the steel will become susceptible to severe attack in the grain-boundary regions. To prevent this, elements which have a greater affinity for carbon than chromium has, were added to the steel. These additional elements formed a stable carbide, the chromium remained present in solid solution, and corrosion resistance was maintained.

The first element tried was tungsten. This element had no structural effect on the steel—*i.e.*, the steel was still wholly austenitic—and was only partially successful in "fixing" the carbon as carbide. Subsequently, titanium was tried with more success. Titanium carbide exists as a separate phase in the 18/8 type steels; the effect of adding titanium is, therefore, equivalent to reducing the carbon content of the steel matrix. Such a reduction in carbon content has the effect of increasing the instability of the austenite, and a steel with sufficient titanium to prevent carbide precipitation is a duplex steel; it contains principally austenite, with some ferrite.

Later work has shown that columbium functions similarly to titanium.

These two elements can therefore be referred to as ferrite-formers when added to an 18/8 chromium–nickel base material. Additions of molybdenum, made to confer additional corrosion resistance in certain special environments (*e.g.*, sulphuric acid), have a similar ferrite-forming effect.

Modern chromium–nickel austenitic steels therefore generally consist of two principal phases, austenite and ferrite, the relative proportions being determined by the composition and, to a lesser extent, by the heat-treatment.

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Mr. Bowen is at Sidney Sussex College, Cambridge, and was formerly in the Metallurgical Section at the Billingham Division of Imperial Chemical Industries, Ltd.

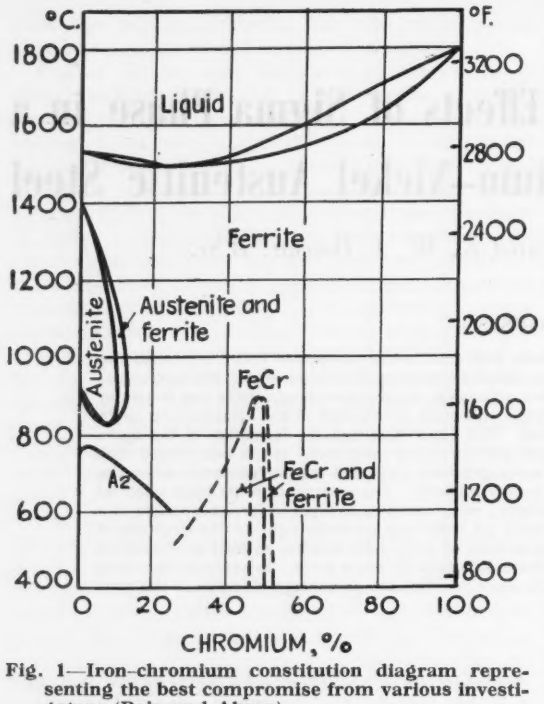

Fig. 1—Iron–chromium constitution diagram representing the best compromise from various investigators (Bain and Aborn)

It has also been shown and the experiments described hereafter confirm that under certain conditions of heat-treatment and composition a third phase may appear which seems to derive from the ferrite. This phase is that referred to previously as probably being the sigma phase mentioned in the literature. Thus the chromium–nickel austenitic steels may consist of: (*a*) austenite, (*b*) austenite and ferrite, (*c*) austenite, ferrite, and sigma, or (*d*) austenite and sigma. In addition, of course, carbides may be present in all these steels.

THE SIGMA PHASE

The existence in the iron–chromium alloy series of a hard, brittle phase of a composition approximating to that of the compound FeCr has definitely been established by a number of investigators in America, Germany, and Britain. The limits of existence of this phase have not been completely defined, particularly at ordinary temperatures, but the general outline of the iron–chromium diagram is shown in Fig. 1. Sigma, as this hard phase has been designated, exists as the sole phase over the composition range 43–48% of chromium by weight at ordinary temperatures, but both above and below these limits of chromium content there are ranges of composition within which the alloy structure consists of alpha solid solution and sigma. The limits of the duplex structure are still very doubtful owing to the slow rate of approach of these alloys to equilibrium. The latest work available on the subject is by Cook and Jones[1] from which Fig. 2 is taken. This diagram shows the phase boundaries of the sigma and alpha phases between 800° and 600° C. as determined by these workers. Cook and Jones show that the sigma phase exists alone in the composition range 44–50 at.-% of chromium but is unstable above 820°C. They also show that sigma can exist between the limits 26 and 71 at.-% of chromium at 600° C. This range of composition is much wider than that reported by previous workers.

In 1927, Bain and Griffiths[2] investigated a number of iron–chromium–nickel alloys. They describe a hard non-magnetic phase which may be produced in alloys covering a wide range of compositions. This phase, which they call the *B* constituent, exists in two forms: (*a*) Massive form—a clear-etching, hard, brittle non-magnetic constituent usually filled with cracks, and (*b*) a troostitic form—a dark-etching dispersion of true *B* in a ferrite matrix.

They concluded that the *B* constituent was developed above 900° C. and probably below 950° C. There is little doubt that the *B* constituent of Bain and Griffiths is the compound FeCr in which some of the iron or chromium atoms have been replaced by nickel.

An excellent summary of information on the occurrence of the sigma phase in alloys of iron, chromium, and nickel is given by Francis B. Foley.[3] A large part of this paper is devoted to the effect of elements other than iron and chromium, principally nickel, on the sigma phase. It is stated that with the addition of nickel to iron–chromium alloys, the sigma phase persists up to 920° C. and that its limits of composition are extended. It is found in equilibrium with austenite as well as ferrite. The nickel appears to replace iron in the FeCr compound so that the iron content of sigma decreases from 60% to 39% while the nickel content increases from nil to 8%.

Foley also describes the work of Franks, Binder, and Bishop,[4] on the effect of molybdenum on the chromium–nickel austenitic steels containing up to 25% of chromium and 23% of nickel. They found that increasing the molybdenum content from 1% to just above 3% extended the range of composition of austenitic steels in which sigma was found to be a stable phase. In steels containing 2·75–3·25% of molybdenum, the ferrite decomposition to the sigma phase was often complete. In their reply to discussion, the writers state that they were able to isolate some sigma phase from a molybdenum-bearing chromium–nickel austenitic steel by electrolytic separation. This particular steel was air-cooled from 1125° C. and then reheated to 870° C. for 672 hr., followed by air-cooling. The compositions of the steel

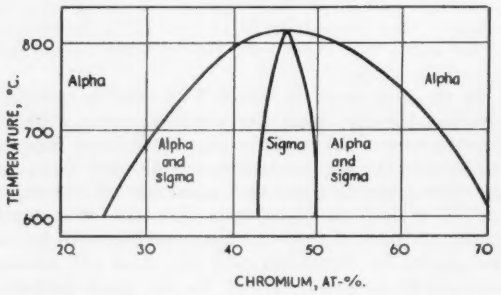

Fig. 2—Part of the iron–chromium diagram (Cook and Jones)

and of the residue separated from it are given below. If it is assumed that the residue consists of the sigma phase then the sigma phase is rich in the ferrite-forming elements :

Elements	Composition of Steel, %	Composition of Residue, %
Chromium	18·22	23·38
Nickel	13·64	5·03
Molybdenum	3·67	12·54
Manganese	1·79	1·44
Silicon	0·59	2·10
Carbon	0·05	0·57
Iron	Remainder	44·4

It will be noted that the sum of the constituents in the residue is only about 89%. The writers give no explanation of this in their paper.

Gow and Harder,[5] investigating commercial alloys of the 25/12 chromium–nickel type, found that the nickel and chromium contents necessary to prevent sigma formation may be expressed by the formula : (Cr% — 16C%)/Ni% must be less than 1·7.

Gow and Harder[5] also produce evidence of the effect of silicon and molybdenum as promoters of sigma formation. They state that silicon in excess of 1% has an effect equivalent to three times its weight of chromium in the 25/12 chromium–nickel casting alloy. For molybdenum the factor is four. In addition, they confirm that the presence of sigma in the chromium irons and in the austenitic steels causes impairment of ductility and in the latter alloys may cause serious impairment of the corrosion resistance.

Foley ends his summary with a reference to methods of detecting sigma. He states that micro-examination is useful only if sigma is present in a fairly large quantity. Its presence is reflected in changes in mechanical and magnetic properties before it can be detected microscopically. He suggests magnetic methods as being the most promising for following the development of sigma formation.

PRESENT INVESTIGATION

Material Tested

A quantity of steel of nominal 18/8/3/Ti composition was reserved for this work. Analysis of the steel gave the following results :

Carbon ...	0·08%	Nickel ...	8·1%
Manganese ...	0·34%	Molybdenum	3·2%
Silicon ...	0·7%	Titanium ...	0·3%
Chromium ...	18·4%	Nitrogen ...	0·027%

General Scheme of the Tests

Preliminary experiments had shown that the formation of sigma in these steels is a function of

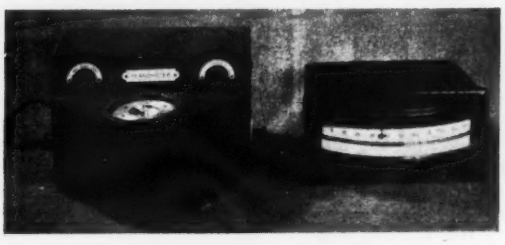

Fig 3—Ferrometer assembly

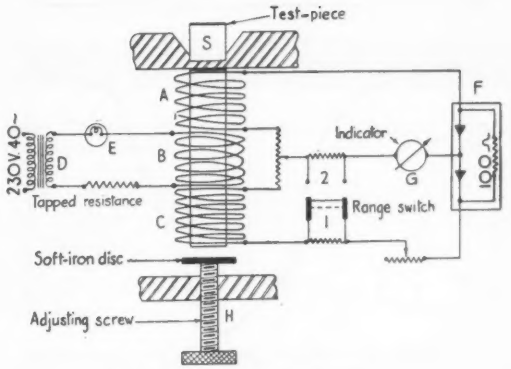

Fig. 4—Ferrometer circuit

time and temperature. Specimens were therefore heated at various temperatures for 4 hr., air-cooled, and the changes produced in microstructure and properties were investigated. The temperature of maximum rate of sigma formation was then selected. Specimens were heated at that temperature for various times and air-cooled.

The changes brought about by heating in the above manner were investigated by five methods : (1) By following changes in the magnetic properties, (2) by X-ray crystallography, (3) by micro-examination, (4) by mechanical tests, and (5) by corrosion tests.

The results of the tests are reported under these five headings.

EFFECT OF INTERMEDIATE HEATING ON THE MAGNETIC PROPERTIES

The Ferrometer

Austenite is non-ferromagnetic and ferrite is strongly ferromagnetic. Therefore 18/8/Ti steel, which is predominantly austenitic but contains some free ferrite, is slightly magnetic, while 18/8/3/Ti steel contains more ferrite and is fairly strongly magnetic. Sigma is non-ferromagnetic and in 18/8/3/Ti steel it is formed from the ferrite so that sigma formation causes a reduction in the ferromagnetism of this austenite–ferrite steel.

A colleague, Dr. W. J. Clark, produced an instrument which would enable the changes in ferromagnetism in a steel to be followed. This instrument was named the Ferrometer and is shown in Fig. 3 with a test-piece in position. Figure 4 illustrates the circuit diagram. It consists essentially of a primary coil *B* and two secondary coils *A* and *C* round a soft-iron core. The primary is energized by alternating current from a transformer *D* with a Barretter lamp *E* to ensure a constant current. The two secondary coils are connected in series through a temperature-compensated rectifier *F* and calibration and zero-adjustment resistances. An indicator *G*, 14 μ amp. full-scale deflection, is connected so as to indicate any out-of-balance current between the two secondary coils. Initially *A* and *C* are balanced by adjusting the position of the soft-iron disc using the screw *H*.

If a non-magnetic material is placed on top of the coils at *S*, when *A* and *C* are balanced, the balance is undisturbed, but if the specimen is magnetic, the

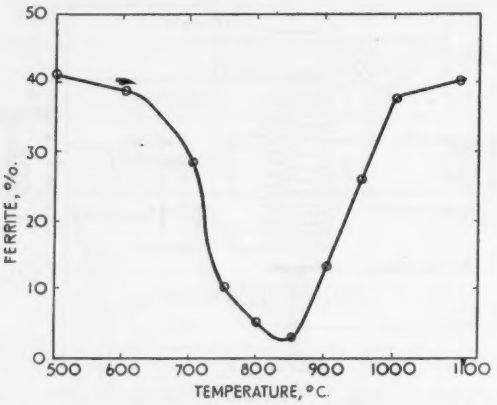

Fig. 5—Relationship between ferrite content and reheating temperature

circuit is thrown out of balance and a reading is obtained on *G*. The instrument is calibrated by using compacts of iron and copper powders in varying proportions. If a specimen of 18/8/3/Ti steel gives a reading the same as that given by a 70/30 copper–iron compact, the 18/8/3/Ti specimen is said to contain 30% of ferrite. It is fully appreciated that there may be valid arguments against assuming that highly alloyed ferrite and pure iron would give the same reading on the Ferrometer and that the difference between the matrices may be ignored, but tests have shown, for instance, that specimens of steel containing 12% of chromium and 2% of carbon and consisting of ferrite and carbide give the same reading as a mild-steel specimen. In addition it is important to remember that the main consideration is the differences between similar specimens which can be brought about by heat-treatment.

Effect of Variation in Re-Heat-Treatment Temperature

Several specimens were water-quenched from 1150° C. and were then reheated in pairs for 4 hr. at temperatures within the range 500–1100° C. and air-cooled. Ferrometer readings were taken after each heat-treatment. The results are embodied in Fig. 5.

Effect of Variation in Time of Reheating at 850° C.

A number of specimens were then water-quenched from 1150° C. and reheated for various times at 850° C., the temperature which caused the maximum reduction in the ferrite content. The results of Ferrometer examination are embodied in Fig. 6. All the specimens were air-cooled from 850° C. and all had 46% of ferrite after water-quenching from 1150° C.

These two sets of tests show that :

(i) When fully softened 18/8/3/Ti steel is reheated for 4 hr. at progressively higher temperatures, starting at 500° C., the ferrite content produced decreases, reaching a minimum value at 850° C. For reheating temperatures above 850° C. the ferrite content increases from this minimum value until at 1100° C. the original ferrite content is substantially attained.

(ii) If the steel is reheated for progressively longer times at 850° C. the ferrite content decreases still further and eventually to zero. The steel is then entirely non-magnetic consistent with the microstructure containing sigma and austenite.

Effect of Rate of Cooling from 1150° C.

The next experiment was designed to test whether the magnetic properties of 18/8/3/Ti steel are affected by different rates of cooling from the normal heat-treatment temperature. Specimens were cooled from 1150° C. at different rates and tested on the Ferrometer. The results are as follows :

Method of Cooling from 1150° C.	Ferrite, %
Water-quenched	55
Air-cooled	44
Furnace-cooled	18

These results show that the ferrite content is reduced by replacing the normal water-quench by air-cooling. Furnace-cooling causes a substantial decrease in the ferrite content. It is, of course, unlikely that this steel would be deliberately cooled from this high temperature in a furnace, but it would be possible to approach this rate of cooling if a heavy section were cooled in air.

Effect of Initial Structure of Steel

The next experiment was devised to test whether a specimen which had been made non-magnetic by long-time heating at 850° C. would return to the magnetic state corresponding to a particular different temperature when it was heated at that temperature. Specimens were heated at 850° C. to give ferrite contents of about 3%.

It was found that a short time at 1150° C. followed by water-quenching was sufficient to restore the magnetic properties.

Four specimens were then water-quenched from 1150° C. and two of them were reheated at 850° C. until they were completely non-magnetic. All four specimens were then finally reheated at 950° C. for 48 hr. The results for pairs of specimens were :

Heat-Treatment	Ferrite, %	
(*a*) W.Q. from 1150° C.	52	52
(*b*) As (*a*), then 48 hr. at 850° C., A.C.	0	0
(*c*) As (*a*), then 48 hr. at 950° C., A.C.	24	25
(*d*) As (*b*), then 48 hr. at 950° C., A.C.	24	24

These results show that the steel tends to attain the same ferrite content on heating at 950° C., whether the initial ferrite content was high or low.*

X-RAY CRYSTALLOGRAPHIC EXAMINATION

Two specimens in the form of 20 S.W.G. wire were prepared for X-ray examination. Both samples were water-quenched from 1150° C. and one was reheated at 850° C. until it was non-magnetic. The X-ray photographs are shown in Figs. 7 (*a*) and 7 (*b*). In Fig. 7 (*a*) will be seen the characteristic lines of austenite ($a_1 = 3{\cdot}580$kX.) and ferrite ($a_0 = 2{\cdot}863$kX). In Fig. 7 (*b*) the ferrite lines are extremely faint, the austenite lines are unchanged, and several new faint lines may be seen. The spacings and intensities of

* Recent work suggests that this tendency to the same ferrite content is attained with certain final reheating temperatures only.

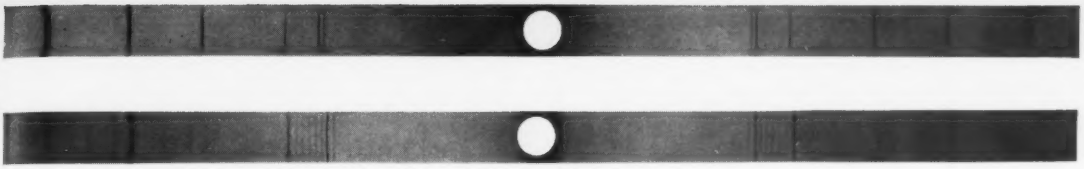

Fig. 7—X-ray photographs from 20-S.W.G. wire specimens ; (a) wire No. 1, austenite and ferrite (reduced in diameter) and (b) wire No. 2, austenite and sigma (reduced in diameter)

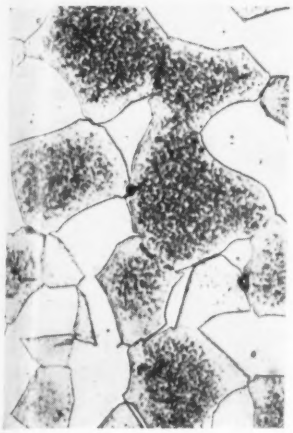

Fig. 10—600° C. Austenite, ferrite (50%), and sigma

Fig. 13—750° C. Etched to show only austenite and sigma ; 20% ferrite

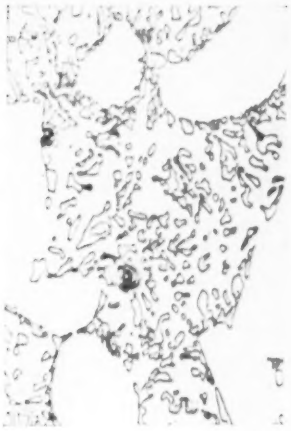

Fig. 16—850° C. Austenite, ferrite (8%), and sigma

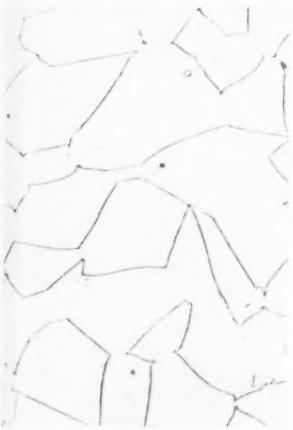

Fig. 9—550° C. Austenite, ferrite (62%), and some submicroscopic sigma

Fig. 12—700° C. Austenite, ferrite (35%), and sigma

Fig. 15—800° C. Austenite, ferrite (14%), and sigma

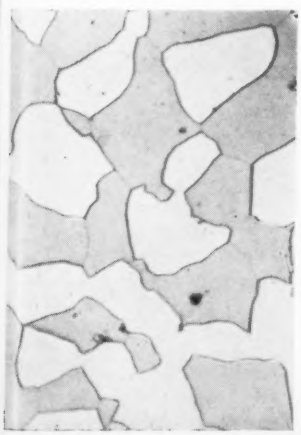

Fig. 8—Heated for 1 hr. at 1150° C., A.C. Austenite and ferrite (66%). Electrolytically etched in (1) 10% oxalic acid plus (2) 70% nitric acid × 400

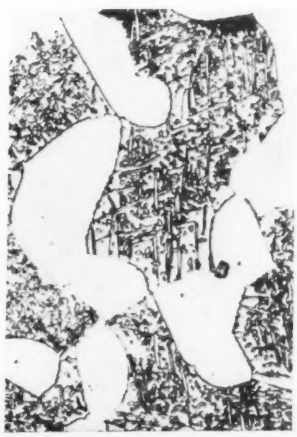

Fig. 11—650° C. Austenite, ferrite (41%), and sigma

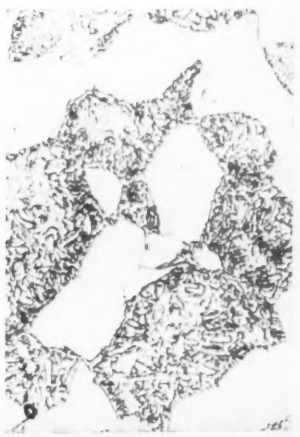

Fig. 14—Same specimen as Fig. 13, but etched to show austenite, ferrite, and sigma

Figs. 9 to 16—Specimens reheated for 4 hr. at various temperatures and air-cooled. Electrolytically etched in 10% oxalic acid × 400

[*Smith and Bowen*

[*To face p. 298*

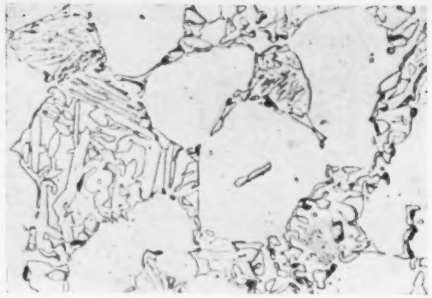

Fig. 17—900° C. Austenite, ferrite (20%), and sigma

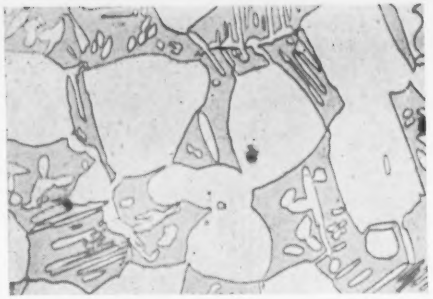

Fig. 18—950° C. Austenite, ferrite (42%), and sigma

Fig. 19—1000° C. Austenite and ferrite (45%)

Fig. 20—1100° C. Austenite and ferrite (48%)

Fig. 21—2½ min. Austenite, ferrite (50%), and sigma

Fig. 22—5 min. Austenite, ferrite (43%), and sigma

Fig. 23—11 min. Austenite, ferrite (40%), and sigma

Fig. 24—15 min. Austenite, ferrite (35%), and sigma

Fig. 25—2½ hr. Etched to show only austenite and sigma; 20% ferrite

Figs. 17 to 20—Specimens reheated for 4 hr. at various temperatures, air-cooled, and etched electrolytically in (1) 10% oxalic acid plus, in the case of Figs. 18, 19, and 20 (2) 70% nitric acid × 400

Figs. 21 to 25—Specimens reheated to 850° C. for various times, air-cooled, and electrolytically etched in 10% oxalic acid × 400

and sigma

Figs. 17 to 20—Specimens reheated for 4 hr. at various temperatures, air-cooled, and etched electrolytically in (1) 10% oxalic acid plus, in the case of Figs. 18, 19, and 20 (2) 70% nitric acid × 400

and sigma

Fig. 25—2½ hr. Etched to show only austenite and sigma ; 20% ferrite

Figs. 21 to 25—Specimens reheated to 850° C. for various times, air-cooled, and electrolytically etched in 10% oxalic acid × 400

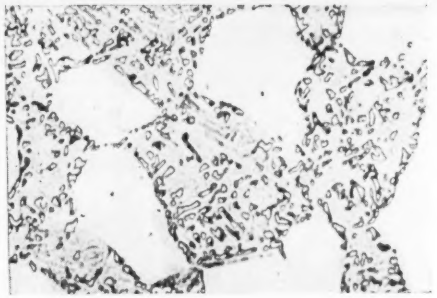

Fig. 26—Same specimen as Fig. 25, but etched to show austenite, ferrite, and sigma

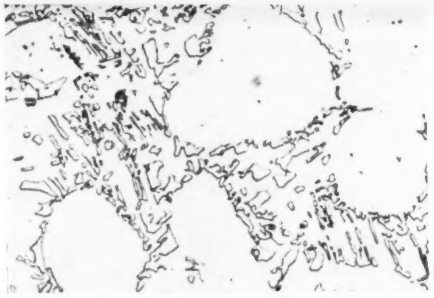

Fig. 27—4 hr. Austenite, ferrite (13%), and sigma

Fig. 28—16 hr. Austenite, ferrite (3%), and sigma

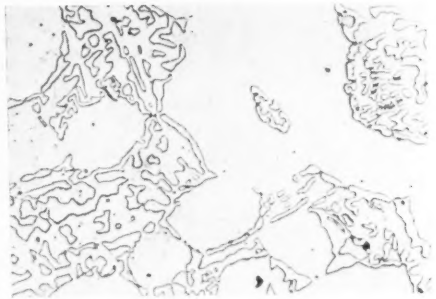

Fig. 29—52 hr. Austenite and sigma ; ferrite, trace

Fig. 30—90 hr. Austenite and sigma ; ferrite, trace

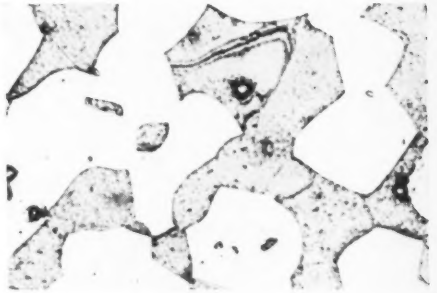

Fig. 31—Reheated to 550° C. for 6 days, A.C. Austenite, ferrite (48%), and sigma

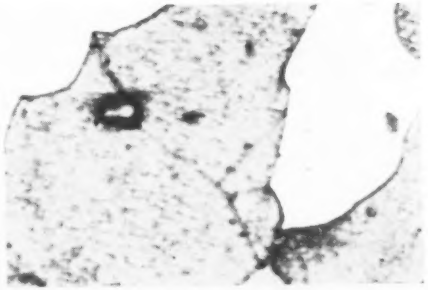

Fig. 32—Same specimen as Fig. 31 × 850

Figs. 27 to 30—Specimens reheated to 850° C. for various times and air-cooled

Figs. 26 to 33—Specimens etched electrolytically in 10% oxalic acid. All except Fig. 32 × 400

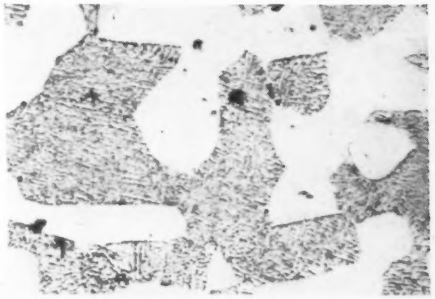

Fig. 33—Reheated to 600° C. for 113 hr., A.C. Austenite, ferrite (36%), and sigma

Fig. 34—4 hr. at 700° C.

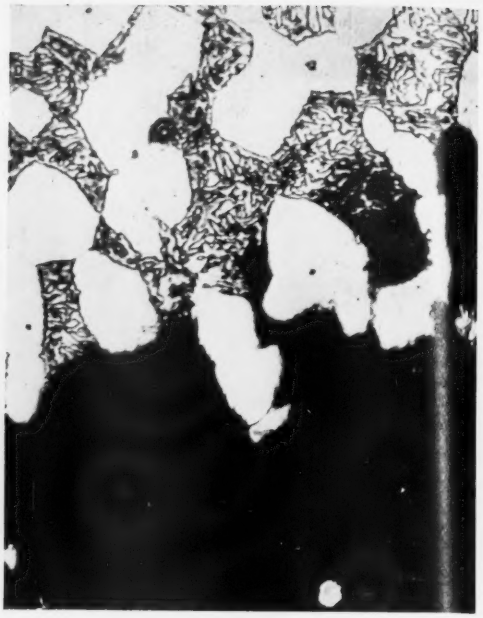

Fig. 35—4 hr. at 750° C.

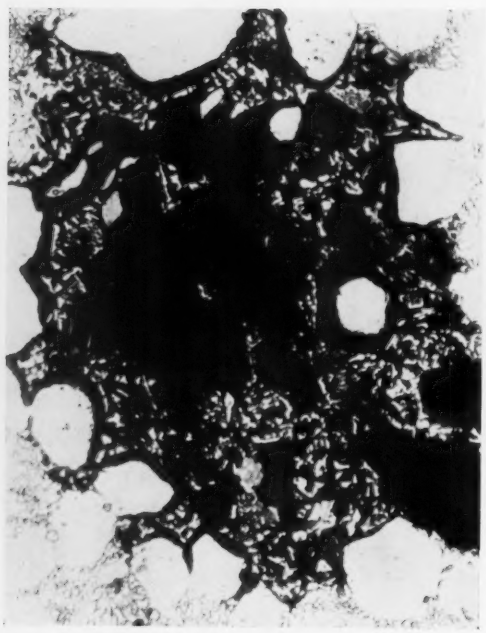

Fig. 36—4 hr. at 800° C.

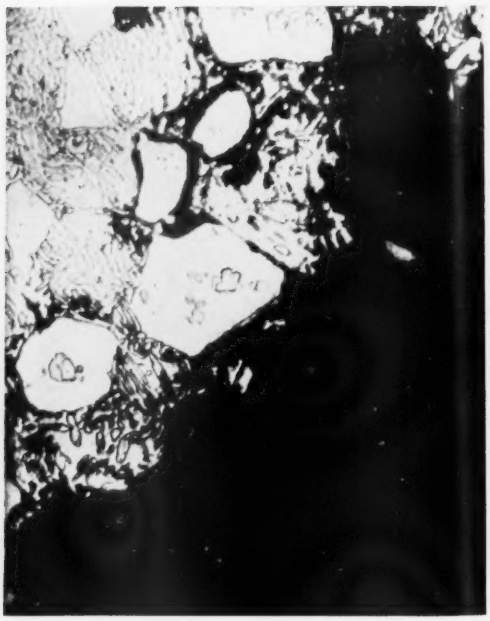

Fig. 37—67 min. at 850° C.

Figs. 34, 35, and 37—Corroded edges of specimens. Fig. 36—Corroded edges of a pit in a specimen. All reheated for various times to various temperatures, air-cooled, and electrolytically etched in 10% oxalic acid × 400

these lines, attributed to the sigma phase present, in 18/8/3/Ti steel are as follows:

Interplanar Spacing, kX.	Line Intensity	Interplanar Spacing, kX.	Line Intensity
2·279	*VVW*	1·392	*VW*
2·124	*VW*	1·259	Trace
1·973	*MVW*	1·241	*M*
1·928	*MW*	1·230	*VW*
1·884	*W*	1·208	*MW*
1·839	*VW*	1·200	*VVW*
		1·189	*VVW*

M = moderate, *MW* = moderately weak, *W* = weak, *MVW* = moderately very weak, *VW* = very weak, and *VVW* = very, very weak.

A search of the literature reveals no table of interplanar spacings for sigma, but Cook and Jones[1] publish one-half of a powder photograph of FeCr which contains groups of lines very similar to those shown in Fig. 7 (*b*). One feature of the powder pattern is the absence of lines of spacings greater than 2·28kX. Such lines would be expected if the unit cell were cubic since the cell edge would be large in order to give the observed multiplicity of lines in the region of 2·28–1·84kX. Attempts to index the photographs on the basis of tetragonal or hexagonal cells of reasonable size also failed. Certain spacings can be accounted for by a cube of side 3·95kX., and the remainder can be roughly grouped around these, suggesting that the true cell is a distorted cube, thereby accounting for the multiplicity of faint lines.

EFFECT OF INTERMEDIATE REHEATING ON MICROSTRUCTURE

Effect of Variation in Re-Heat-Treatment Temperature

Micro-examination of the 18/8/3/Ti type of steel is normally made difficult by the small grain-size of the steel in the wrought condition. With a view to easing this difficulty all specimens for the microstructural investigation were heated to 1200–1250° C. for several days in order to increase the grain-size. The specimens were then heated to 1150° C. and water-quenched before reheating to intermediate temperatures. One-inch diameter bar was used so that on machining down to $\frac{5}{8}$ in. dia. all surface effects were removed. Magnetic evidence suggests that pretreatment at 1200–1250° C. does not appreciably influence the subsequent formation of the sigma phase on reheating. This pretreatment, however, was followed by the standardized treatment of heating to 1150° C. and water-quenching, in order to ensure that the amounts of ferrite and austenite present at the start of this experiment were similar for all specimens.

All microstructures were produced by etching electrolytically in 10% oxalic acid. By adjusting etching conditions it was found possible in some instances to develop the structure of the sigma phase alone and then with additional etching to reveal the structure of the ferrite grains. When needed, contrast between austenite and ferrite, and between ferrite and sigma, was obtained by following an etching in oxalic acid with an electrolytic etching in 70% nitric acid. This second etching operation darkened the ferrite grains but did not colour either austenite or sigma. The microstructure in the condition as water-quenched from 1150° C. consisted of austenite and ferrite and is shown in Fig. 8 at × 400. The grain-size is large and the grain boundaries are definite.

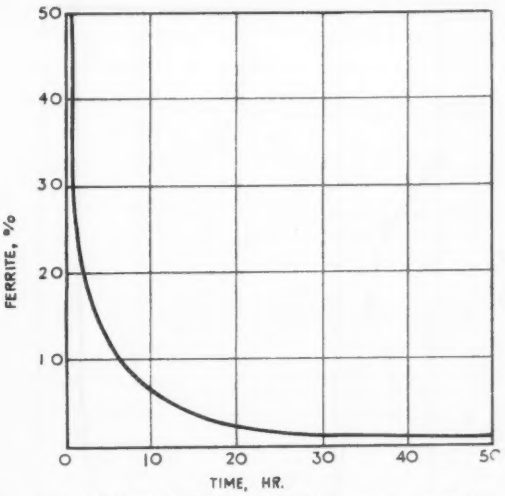

Fig. 6—Relationship between ferrite content and time of reheating at 850° C.

Specimens of the large grain-size steel were then reheated at temperatures within the range 500–1100° C. for 4 hr., air-cooled, and examined microscopically. Figures 9 to 20 show photomicrographs of the resulting structures, the corresponding ferrite contents being given underneath the photomicrographs. Reheating to 500° C. caused a slight fall in the ferrite content, but no apparent change in microstructure. At 550° C., although there was a fall of 4% in the ferrite content, there was still no noticeable effect on the microstructure, as shown in Fig. 9. Heating for 4 hr. at 600° C. reduced the ferrite content to 50%, and Fig. 10 shows that the ferrite grains are darkened by a fine dispersion of sigma particles tending to concentrate at the centre of the grains. This structure in the ferrite grains might fit the description used by Bain and Griffiths[2] for the troostite form of their *B* constituent. At 650° C. the sigma phase appears in the form of lamellæ along the crystallographic planes, resembling the Widmanstätten structure. It will be noted that the grain boundaries between the austenite and the original ferrite are still quite plainly outlined. At 700° C. the sigma phase is appearing as small globules at the grain boundaries while some coalescence of the lamellæ in the interior of the ferrite grains has occurred. At 750° C. the sigma phase appears as well-defined particles both at the boundaries and at the interior of the original ferrite grains. Figure 13 shows the structure etched to show only austenite and sigma, while Fig. 14 shows austenite, sigma, and the transforming ferrite constituent. At 800° C., and still more so at 850° C., the sigma particles are quite discrete and the structure consists of austenite and sigma closely associated with small amounts of ferrite, 14% and 8% respectively.

The ferrite content is at a minimum at 850° C., as reheating at 900° C. reduces the ferrite content to 20%—*i.e.*, the same figure as is produced by reheating to 750° C. Figure 17 shows the 900° C. structure at a magnification of 400, while microscopical

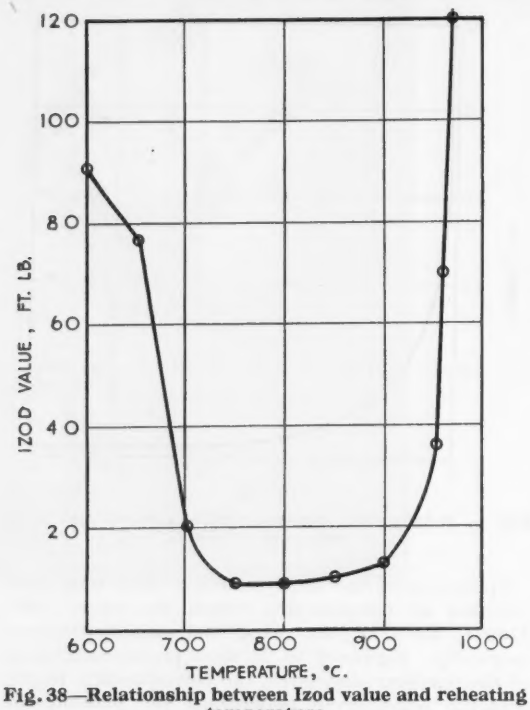

Fig. 38—Relationship between Izod value and reheating temperature

examination at greater magnification shows angular sigma particles to be closely associated with the ferrite areas. At 950° C. a few sigma particles are present and the ferrite grain boundaries are definite, while areas of austenite exist inside the ferrite grains. At 1000° C. no sigma particles are present and the areas of austenite inside the ferrite grains have decreased in number. At 1100° C. further decrease in the number of austenitic areas within the ferrite grains has occurred and some ferrite grains are free from included austenite.

Effect of Variation in Time of Reheating at 850° C.

The next series of photomicrographs, Figures 21 to 30, shows the effect on the structure of reheating at 850° C. for increasing times, followed by air-cooling. It will be seen that a period of 2½ min. at 850° C. is sufficient to show a visible change in the ferrite areas. The new phase appears as aggregates of small globules and acicular lamellæ growing from the boundaries of the ferrite grains, particularly from the common grain boundary between two ferrite grains. Figs. 22 and 23 show further growth of lamellæ along crystallographic planes, and Fig. 24 shows that after 15 min. at 850° C. the ferrite grain boundaries begin to lose their sharpness. The remaining photomicrographs illustrate the gradual transformation of the ferrite constituent and the coagulation of the sigma phase until the structure consists only of austenite and sigma which is boldly outlined in relief as shown in Fig. 30.

Effect of Long-Time Reheating at 550° C. and 600° C.

It was decided to investigate whether long-time reheating at 550° C. would produce an effect visible under the microscope. It had already been shown that reheating a fully softened specimen at 550° C. reduced the amount of ferromagnetic phase, but microexamination showed no structural change. Figure 31 shows the microstructure of a specimen after reheating for 6 days at 550° C., followed by air-cooling, and Fig. 32 shows the same structure at a higher magnification. The ferrite grains are covered with a dispersion of extremely fine particles and it will be noted that the ferrite content has fallen to 48%.

A fully softened specimen was then reheated at 600° C. for 113 hr. The ferrite content decreased to 36% and the structure showed a fairly uniform distribution in the ferrite of slightly acicular sigma, as shown in Fig. 33.

EFFECT OF INTERMEDIATE REHEATING ON THE MECHANICAL PROPERTIES

Some preliminary experiments showed that the formation of the sigma phase had no significant effect on the tensile strength and that it slightly decreased the ductility as measured by elongation and reduction in area. Results of hardness tests (load 50 kg.) made on a series of specimens together with reheating temperatures, were as follows :

Reheating Temp., °C.	Ferrite, %	Hardness, V.P.N.
Nil	43	200
500	43	220
550	42	199
600	37	200
650	33	203
700	30	211
750	11	229
800	5	231
850	3	237
900	12	217
950	25	210
1000	37	186
1100	40	184

For these hardness tests the specimens were first water-quenched from 1150° C. and then reheated at the indicated temperature for 4 hr., followed by air-cooling to room temperature. An investigation of the variation of hardness with time at the temperature at which the sigma phase is formed most rapidly, *i.e.*, 850° C., revealed that, whereas a time of 1½ hr. at the temperature, followed by air-cooling, produced a hardness of 232 V.P.N., longer times at the temperature did not increase this value. These hardness figures, including the apparent increase in hardness after heating at 500° C., were entirely confirmed by results obtained from steels of similar analysis.

In order to explore the effect of reheating for varying times at 850° C. on impact resistance, Izod test-pieces were cut from bars which had been water-quenched from 1150° C. and then reheated for various times at 850° C. and air-cooled. The results were :

Time at 850° C.	Izod Value, ft. lb.
Nil	120 unbroken
3 min.	58
5 min.	20
15 min.	17
30 min.	16
60 min.	13
3 hr.	13
7 hr.	11
15 hr.	9
40 hr.	8
91 hr.	7
158 hr.	8

It will be seen that a very short reheating time at 850° C. causes a rapid fall in impact value. Longer times at 850° C. reduce the value to a very low figure. It is evident that the impact value is very sensitive to the presence of even small amounts of sigma and it is suggested that if the Izod value of a specimen is as high as 120 ft. lb., no sigma is present.

Impact specimens were then cut from bars which had been reheated within the range 600–1100° C. Figure 38 shows that as the reheating temperature is increased from 600° C., the impact-value curve falls fairly rapidly to a wide trough covering the temperature range 750–900° C. For reheating temperatures above 900° C. there is an extremely rapid recovery in the impact value which becomes 120 ft. lb. for a reheating temperature of 970° C. Since the impact value is so sensitive to the presence of small amounts of sigma, the curve in Fig. 38 shows that for a reheating period of 4 hr. the amount of sigma formed increases as the reheating temperature rises from 600° C. The maximum sigma formation is in the temperature range 750–900° C. For reheating temperatures above 900° C. the amount of sigma formed decreases rapidly until at 970° C. none is formed. The curve checks closely with that shown in Fig. 5, but the comparison shows that the impact value is not sensitive to small changes at low ferrite and high sigma percentages.

EFFECT OF RE-HEAT-TREATMENT ON THE CORROSION RESISTANCE

Effect of Variation of Reheating Temperature

The first set of tests which showed the effect of intermediate reheating on the corrosion resistance of 18/8/3/Ti steel was carried out with 25% sulphuric acid at 40° C. The acid was 25% by weight and was made up by adding 13·7 ml. of concentrated sulphuric acid (sp. gr. 1·84) to 75 ml. of water. Immersion in this solution was recognized to be a very severe corrosion test as the steel would not be used in such a solution in practice. Its selection, however, was deliberate, with the object of achieving maximum contrast in results. Specimens in bar form were water-quenched from 1150° C. and then reheated for 4 hr. at the intermediate temperatures and air-cooled. Ferrometer-size specimens were then cut from the bars and given a fine machine finish. Just before immersion in the corrosive medium they were given a light rub on all surfaces with medium-rough emery paper. The results after a three weeks' test are shown in Fig. 39 and in Table I.

It will be noted that the maximum weight loss occurs at the reheating temperature of 750° C. It was found that except where the weight loss was very great, there was a tendency for specimens to corrode during the first period of immersion and then to become passive. It must be clearly understood that the corroding medium used in these tests—25% sulphuric acid at 40° C.—was chosen because of the contrasting results it produces. The steel would not be used in this environment in industry.

The tests were repeated using the following corrosive conditions: (*a*) 5% sulphuric acid at room temperature and (*b*) 5% sulphuric acid at 40° C. The specimens tested in 5% sulphuric acid at room temperature were left undisturbed for four months. The weight losses were slight and variable but showed no correlation with heat-treatment temperatures. The highest loss was equivalent to only 0·05 mm./year, and it was evident that the conditions were not selective. The results of the corrosion tests in 5% sulphuric acid at 40° C. were very similar.

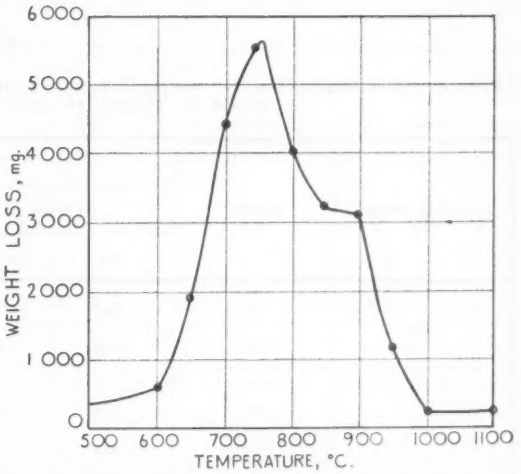

Fig. 39—Relationship between weight loss in 25% sulphuric acid at 40° C. and reheating temperature

Effect of Variation of Time of Reheating at 850° C.

Specimens were water-quenched from 1150° C. and then reheated for various periods of time at 850° C., followed by air-cooling. The method of preparation of the Ferrometer specimens prior to immersion in 25% sulphuric acid at 40° C. was similar to that described above. The results of these corrosion tests are shown in Table II. It is evident that the presence of quite small amounts of sigma, formed by heating at 850° C. for short periods of time, is sufficient to reduce the corrosion resistance very greatly in this strongly corrosive medium. Actually the effect of heating for 2½ min. was indeterminate as one of the duplicate samples showed a weight loss equivalent to only 0·04 mm./year, while the other showed a weight loss equivalent to 2·5 mm./year. Heating for 5 min. at 850° C. effectively destroys the corrosion resistance while increase in time at temperature causes little further impairment in this property.

Effect of Rate of Cooling from 1150° C.

Since different rates of cooling from 1150° C. gave different Ferrometer readings, specimens in these different conditions were given the usual surface preparation and immersed in 25% sulphuric acid at 40° C. for 14 days. The corrosion losses are given below:

Method of Cooling from 1150° C.	Ferrite, %	Loss, mm./yr.
Water-quenched	55	0·5
Air-cooled	44	1·0
Furnace-cooled	18	7·3

Plant Corrosion Tests

To supplement the laboratory tests, some plant corrosion tests have been carried out. Specimens of

Table I

EFFECT OF VARIATION OF REHEATING TEMPERATURE ON THE CORROSION RESISTANCE OF 18/8/3/TI STEEL IN 25% SULPHURIC ACID AT 40° C.

Reheating Temp., °C.	Ferrite, %	Loss after:					
		1 week		2 weeks		3 weeks	
		mg.	mm./yr.	mg.	mm./yr.	mg.	mm./yr.
500	40	267	1·7	267	0·9	267	0·6
	40	443	2·8	449	1·4	449	1·0
600	39	370	2·4	557	1·8	562	1·2
	39	352	2·2	658	2·1	668	1·4
650	38	771	4·9	1389	4·4	1828	3·9
	38	883	5·7	1538	4·9	2006	4·3
700	35	1626	10·4	3214	10·3	4630	9·9
	35	1458	9·3	2881	9·2	4032	8·6
750	18	1984	12·7	3837	12·3	5497	11·7
	18	2120	13·6	3998	12·8	5521	11·8
800	12	1580	10·0	2943	9·4	4176	8·9
	12	1517	9·7	2866	9·2	4020	8·6
850	7	1268	7·8	2335	7·5	3215	6·8
	7	1362	8·7	2314	7·4	3242	6·9
900	11	1398	8·9	2330	7·5	3077	6·6
	11	1388	8·9	2285	7·3	3125	6·6
950	20	1145	7·3	1145	3·7	1145	2·4
	20	1088	7·0	1088	3·5	1088	2·3
1000	38	217	1·4	217	0·7	217	0·5
	38	318	2·0	318	1·0	318	0·7
1100	40	526	3·4	526	1·7	526	1·1
	40	211	1·4	211	0·7	211	0·4
Nil	40	162	1·0	162	0·5	162	0·3
	40	485	3·1	485	1·6	485	1·0

18/8/3/Ti steel in the form of 10-gauge sheet 6 × 3 in. were exposed under plant conditions to a saturated solution of ammonium sulphate containing a small percentage of free acid, and boiling under reduced pressure. The conditions of the specimens were as follows :

(*a*) Specimen water-quenched from 1150° C.

(*b*) Specimen reheated at 750° C. for 30 min. and air-cooled.

(*c*) Specimens (*a*) and (*b*) in electrical contact with each other.

(*d*) Specimen in condition (*a*) in contact with 18/8/Ti steel.

(*e*) Specimen in condition (*a*) as welded, with 18/8/3/Cb electrodes.

(*f*) Water-quenched from 1150° C., but one-half cold worked.

Table II

EFFECT OF VARIATION OF TIME OF REHEATING AT 850° C. ON THE CORROSION RESISTANCE OF 18/8/3/TI STEEL IN 25% SULPHURIC ACID AT 40° C.

Time at 850° C.	Ferrite, %	Loss after:							
		1 week		2 weeks		3 weeks		4 weeks	
		mg.	mm./yr.	mg.	mm./yr.	mg.	mm./yr.	mg.	mm./yr.
2½ min.	50	28	0·18	28	0·09	28	0·06	28	0·04
	50	675	4·3	1581	5·1	1581	3·4	1581	2·5
5 min.	43	529	3·4	1503	4·8	1900	4·1	2356	3·8
	43	779	5·0	1758	5·6	2154	4·6	2502	4·0
11 min.	40	615	4·0	1724	5·5	2240	4·8	2654	4·1
	40	582	3·7	1650	5·3	1860	3·9	2244	3·6
15 min.	35	586	3·7	1566	5·0	2050	4·3	2503	4·0
	35	681	4·4	1794	5·7	2257	4·8	2722	4·4
67 min.	23	893	5·7	2114	6·8	2748	5·9	3357	5·4
4 hr.	13	1037	6·6	2401	7·7	3045	6·5	3671	5·9
	13	960	6·1	2328	7·5	3017	6·4	3695	5·9
16 hr.	4	1033	6·6	2102	6·7	2607	5·6	2622	4·2
	3	1050	6·7	2130	6·8	2673	5·7	2679	4·3
22 hr.	1	969	6·2	2201	7·0	2740	5·8	3210	5·1
	1	1191	7·6	2363	7·6	2930	6·2	3439	5·5
52 hr.	Trace	865	5·5	2113	6·8	2609	5·6	2609	4·2
90 hr.	Trace	935	6·0	2214	7·1	2744	5·8	2744	4·4
	Trace	988	6·3	2158	6·9	2679	5·7	2679	4·3
W.Q. from 1150° C.	54	25	0·16	27	0·09	27	0·06	27	0·04
	54	18	0·12	18	0·06	18	0·04	18	0·03

The weight losses in all cases were negligible, indicating that under the given plant conditions the presence of the sigma phase did not decrease the corrosion resistance of 18/8/3/Ti steel to a saturated solution of ammonium sulphate, a liquor for which it would be used in industry.

Micro-Examination of Corroded Specimens

In order to investigate the mode of corrosion, sections for micro-examination were cut from various corroded specimens. Figure 34 shows the corroded edge of a specimen which has been reheated at 700° C. for 4 hr. and air-cooled ; Figure 35 shows the corroded edge of a specimen which has been reheated at 750° C. for 4 hr. and air-cooled ; and Fig. 36 shows the edges of a shallow corrosion pit in a specimen which has been reheated at 800° C. for 4 hr. and air-cooled. The corroded end of the specimen was polished so as to leave some of the corrosion pits still visible on the polished surface. Figure 37 shows the corroded edge of a specimen which has been reheated at 850° C. for 67 min. and air-cooled. In all cases the corroding medium was 25% sulphuric acid at 40° C.

The most obvious feature of all the above photomicrographs is that there is selective corrosion of the original ferrite grains which now consist of sigma together with ferrite lower in chromium, molybdenum, and silicon contents than the original ferrite. It is not easy to determine whether it is the sigma particles or the ferrite matrix which is being attacked. Study of the microsections suggests that, initially, corrosion is occurring in the region of the sigma-phase boundaries, but further work is being done on this aspect of the investigation.

DISCUSSION OF EXPERIMENTAL RESULTS

Occurrence of the Sigma Phase

The presence of a phase other than austenite and ferrite in a commercial chromium–nickel austenitic steel containing molybdenum has been confirmed. This third phase appears in 18/8/3/Ti steel reheated in the temperature range 500–970° C. It is a hard phase and its presence reduces the impact resistance of the steel. It is non-magnetic, and X-ray investigation suggests that it is analogous to the FeCr phase occurring in certain iron–chromium alloys. The FeCr phase has been designated the sigma phase and, in line with other investigators, it has been decided to retain this name for the analogous phase occurring in the chromium–nickel austenitic steels.

Formation of the Sigma Phase

The steel used for the investigation was one based on the 18/8 chromium–nickel austenitic steel, but containing 3% of molybdenum to confer resistance to sulphuric acid, and titanium to stabilize the carbon as titanium carbide. This steel is normally supplied in the fully softened condition, *i.e.*, water-quenched from 1150° C. In this condition the structure consists of austenite and ferrite, the proportions of which may vary according to slight variations in composition and previous treatment. Sigma is formed in the ferrite areas when the steel is reheated in the range 500–970° C. The form taken by the sigma phase varies according to the temperature and the time at temperature, the maximum rate of formation being at about 850° C.

After only 2½ min. at 850° C. a structural change begins from the grain boundaries, particularly those boundaries which are common to two ferrite grains. The change moves towards the centre of the grains as plates or needles along the crystallographic planes. A longer time of reheating reveals that the change in structure consists of the formation of a third phase within the ferrite grains. Further increase in the time at 850° C. causes increase in size of the particles of the new phase and eventually the grain boundaries between the original ferrite and the austenite vanish. The structure then apparently consists of the new phase closely associated with some ferrite and austenite. After a still longer time the steel becomes completely non-magnetic and the structure consists of austenite and hard particles of the new phase. This new phase is the sigma phase and the following is an attempt to describe its mode of formation.

No reference can be found in the literature to any work on the composition of the ferrite and the austenite in the chromium–nickel–molybdenum austenitic steels, but it seems reasonable to assume that the ferrite will be rich in the ferrite-forming elements such as chromium, silicon, molybdenum, and titanium, while the austenite will be rich in nickel. It would appear from the literature that the ferrite-forming elements are also sigma-forming elements.

When 18/8/3/Ti steel consisting of austenite and ferrite is reheated to 850° C. it tends to assume its equilibrium structure of austenite plus sigma. The sigma forms from the ferrite, the transformation starting at the grain boundaries and the crystallographic planes. It is suggested that the transformation is a diffusion phenomenon. The sigma-forming elements, *e.g.*, chromium, molybdenum, and silicon, diffuse to the areas in which sigma is forming and nickel diffuses away from these areas. Thus at an intermediate stage, such as is illustrated in Fig. 23, the original ferrite grains show a duplex structure. One constituent consists of a phase rich in chromium, molybdenum, and silicon, which has the sigma lattice and is non-magnetic ; the other consists of ferrite which is depleted in these elements and enriched in nickel. Eventually, however, the composition of this latter constituent becomes so high in nickel that the ferrite-to-austenite change takes place and the structure again becomes duplex, consisting of austenite and sigma after a long period at 850° C. (*see* Fig. 30).

In order completely to study the effect of reheating the steel at different temperatures it would be necessary to reheat specimens until equilibrium had been attained at each temperature. This might involve long reheating times at the lower temperatures and has not yet been carried out, but study of the structures obtained when samples were reheated for 4 hr. at each temperature allows certain observations to be made. One important conclusion is that a change in the magnetic properties can occur on reheating at 500° C. before any change in microstructure is apparent. A longer time at 550° C. further reduces the magnetism and causes the appearance of finely dispersed sigma in the ferrite. The structure shown in Fig. 10 indicates

that, at lower temperatures, sigma forms at the centre of the grain rather than at grain boundaries. At 650° C. the acicular formation appears, and up to 850° C. the progress of formation of sigma seems to follow the lines of the previous paragraph. At 950° C. the amount of sigma is very much reduced, while at 1000° C. and above, none is visible.

Effect of Sigma on the Properties of 18/8/3/Ti Steel

It has been shown that the presence of sigma in 18/8/3/Ti steel causes a slight increase in hardness and a very appreciable fall in impact resistance. In certain strong corrosive media the corrosion resistance may be adversely affected by the presence of sigma, but it must be emphasized that the laboratory tests have not shown any deterioration in corrosion resistance of heat-treated samples tested in liquors in which 18/8/3/Ti steel would normally be used, *e.g.*, 5% sulphuric acid at 40° C. The presence of quite small amounts of sigma, however, substantially reduces the resistance of the steel to a stronger corrosive medium, 25% sulphuric acid at 40° C. It might, therefore, be argued that the effect of the presence of sigma on the corrosion resistance of 18/8/3/Ti steel in liquors in which it would normally be used is not sufficient to be of practical significance. Plant experience has, nevertheless, shown that this is by no means the case. It is well known that the chromium–nickel austenitic steels occasionally give very erratic results, especially in "border-line" liquors, and they are particularly sensitive to minor constituents in liquors, especially if these are of an oxidizing or reducing nature. In fact, one of the principal difficulties encountered in the laboratory testing of these steels is to duplicate plant conditions. In support of this argument the following two cases are quoted :

(i) A plant for washing oil with cold 8% sulphuric acid was constructed in 18/8/3/Ti steel. Severe corrosion resulted, especially at the heat-affected zone of the welds. This corrosion was ascribed to the reducing nature of the oil.

(ii) Heavy corrosion was found at the heat-affected zone of a welded tee piece in 18/8/3/Ti steel carrying 8% sulphuric acid. The temperature and possibly the acid concentration were liable to vary as the fitting was close to the location in which the acid and water mixed, but the significant fact is that the corrosion was confined to the heat-affected zone.

It will therefore be appreciated that in a steel which is subject to varying conditions of this nature, the possible appearance of a further adverse factor such as the sigma phase is of great practical importance.

The fact that maximum corrosion occurs at 750° C., while maximum sigma occurs at 850° C., is of great interest, but further tests will be needed before adequate comment can be made.

With further work in progress it was decided that the results obtained to date should be published in order to sound a warning note. The conclusions to be drawn at this stage must necessarily be of a somewhat general nature.

CONCLUSIONS

(1) The presence of the sigma phase in 18/8/3/1 chromium–nickel–molybdenum–titanium steel has been confirmed by crystallographic, magnetic, and microscopical evidence.

(2) Crystallographic evidence suggests that the structure of the sigma phase is that of a distorted cube.

(3) The sigma phase is formed in 18/8/3/Ti steel by reheating in the temperature range 500–970° C.

(4) The sigma phase is formed from the ferrite by a diffusion process and varies in form according to the time and temperature of its formation.

(5) The temperature of maximum rate of reduction of ferrite content is 850° C., and prolonged reheating at this temperature will remove all the ferrite leaving a microstructure consisting of austenite and sigma.

(6) The formation of the sigma phase by reheating in the temperature range 500–970° C. is accompanied by an increase in hardness and a marked decrease in impact resistance.

(7) The effect of the presence of the sigma phase on the corrosion resistance of 18/8/3/Ti steel in media for which it would normally be used is not appreciable. It has, however, been shown that in stronger liquors, *e.g.*, 25% sulphuric acid at 40° C., the presence of the sigma phase greatly reduces the corrosion resistance of the steel. It is well known that the chromium–nickel austenitic steels are particularly sensitive to slight changes in liquor composition and temperature, and in such circumstances the presence of the sigma phase in this steel constitutes a further corrosion hazard.

Acknowledgments

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The Production of Nodular Graphite Structures in Cast Iron

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SYNOPSIS

A study has been made of the production of nodular structures in nickel–iron–carbon alloys and it was found that additions of cerium to the molten alloys gave, on solidification, nodular structures in hyper-eutectic alloys even with very low nickel contents. The microstructures of such cerium-treated alloys have been described in detail. When the alloys contained appreciable amounts of sulphur, no nodular structures were obtained.

Attempts to produce nodular structures, by adding cerium to low sulphur hypo-eutectic cast irons, were only partially successful, but when hyper-eutectic irons were treated, structures consisting of hyper-eutectic spherulites and quasi-flake graphite were obtained. With increasing amounts of cerium in such irons the mechanical properties show a progressive improvement. Examples are given of the influences of cerium in hyper-eutectic unalloyed irons and in austenitic irons. The influence of sulphur upon the cerium treatment is discussed and the general composition requirements for the production of nodular structures in the as-cast state are dealt with.

Cerium is a desulphurizer and a powerful carbide stabilizer and one of its functions in producing nodular graphite structures is to reduce the sulphur content of the iron to a relatively low value. The mechanism of solidification of these irons is dealt with, and the hyper-eutectic graphite is shown to form in the liquid, with a spherulitic structure. The quasi-flake graphite forms by the decomposition of a white iron eutectic after solidification. In the vicinity of the hyper-eutectic spherulites the eutectic graphite is deposited upon the already existing nodules.

When the number of hyper-eutectic nodules is increased artificially no quasi-flake graphite forms. A process for accomplishing this has been developed involving the addition of a graphitizing inoculant after the cerium addition. This treatment gives irons having the whole of the graphite in the nodular form. The mechanical properties of such irons are very good and several examples are given to illustrate this.

The cerium may be added to cast iron in the form of *mischmetall* and the treatment must be applied to the molten metal shortly before casting. Cerium is lost on remelting and a reversion to normal flake graphite structures occurs.

Grey cast irons containing nodular structures in the as-cast state are referred to as "nodular cast irons." Previously the only method available for producing such structures was by the lengthy annealing of white cast iron.

Introduction

In previous papers,[1,2] the present investigators have discussed the possibility of producing nodular graphite structures in cast iron without heat-treatment. This work has been continued and as a result a process has been developed by the application of which grey cast irons can be produced having wholly or partially nodular or spherulitic graphite structures in the as-cast state. The object of this report is to give an account of the work leading up to this discovery, to describe the essential features of these alloys and to indicate the limiting conditions under which the process is operable. No attempt will be made to deal with the commercial application of the process or to give a detailed description of the special mechanical properties of cast irons having nodular graphite structures. These features will be made the subject of further papers at a later date. The process referred to in this account has been made the subject of various British, British Empire, and foreign patent applications and at the time of writing it is at the stage of experiment on an industrial scale.

In normal grey cast iron the graphitic carbon, which confers upon the material its characteristic properties of brittleness, non-ductility, and non-malleability, is in the form of flakes or lamellæ of various sizes, according to casting section size, rate of cooling, composition, and melting procedure. These graphite flakes interrupt the continuity of the metallic matrix, and, by acting as stress raisers, reduce the mechanical properties of the aggregate.

In the past, nodular graphite structures have been produced in malleable cast iron by the heat-treatment of white iron castings at elevated temperatures. In the malleable-iron process the cementite of the white iron decomposes slowly at elevated temperatures to give graphite in a nodular form. These nodules are roughly spheroidal in shape and, therefore, in contrast to the flake graphite in grey cast irons, do not interrupt to any marked degree the continuity of the metallic matrix, and so a material of relatively good shock-resistance and ductility is obtained. The nodular graphite, or temper carbon, in malleable cast iron can exist in two different forms: when the sulphur of the iron exists as manganese sulphide each nodule consists of an aggregate of small graphite flakes; but when the sulphur exists predominantly as iron sulphide (FeS) the nodules are spherulitic. These two structures have been adequately described and illustrated elsewhere.[3,4] Hitherto the thermal treatment of a solid, white cast iron has been the only known way of producing nodular-graphite structures at will.

The present investigators have, however, shown[1,2] that spherulitic nodular structures do occasionally

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occur in as-cast grey cast irons on a small scale, although it was not possible to control their production. The nodules which were observed occurred in hypereutectic cast irons which had been subjected to marked undercooling and also associated with inverse chill in irons containing undercooled graphite. During the course of this preliminary work, a study was made of graphite formation in the analogous nickel–carbon and cobalt–carbon alloys and it was found that the addition of calcium and magnesium to these alloys caused the formation of spherulitic graphite structures. Similarly, by the rapid cooling of nickel–carbon alloys, spherulitic graphite structures were produced. It was suggested that the action of the elements calcium and magnesium in giving nodular structures in nickel–carbon alloys is due to these elements causing undercooling and stabilization of the nickel carbide forming on solidification, so that it decomposes at a lower temperature than that required to give undercooled graphite. Calcium and magnesium did not give spherulitic graphite structures in nickel–carbon alloys when the sulphur content was high, nor in nickel–iron–carbon alloys when the iron content exceeded about 50%. In nickel–carbon alloys both the hyper-eutectic and the eutectic graphite were obtained in the spherulitic form. In the course of an extensive investigation it was shown that the analogies existing between nickel–carbon alloys on the one hand and cast iron on the other were very close, and on this basis, with the knowledge of how spherulitic graphite structures could be produced in nickel–carbon alloys, the following suggestion was put forward :

> " The production of completely spherulitic structures in cast iron requires an iron which will undercool to give the acicular white-iron structure on solidification and the presence of an alloying element which will cause it to persist until a temperature probably within the range 800–1050° C., beyond which the carbide would be permitted to decompose."

From this point the further investigation described in this paper begins. It is suggested that a better appreciation of the problem and of the line of investigation chosen will be obtained if the previous papers[1,2] are studied.

THE PRODUCTION OF SPHERULITIC GRAPHITE STRUCTURES IN IRON–NICKEL–CARBON AND IRON–CARBON ALLOYS

It was found by experiment that calcium and magnesium would not dissolve in cast irons, nor in iron-rich iron–nickel–carbon alloys to give spherulitic graphite structures and so, since it was believed that it should be possible to produce these structures in cast irons by a similar process, a search was made for other elements which would give nodular structures when added to pure nickel–carbon alloys. Several such elements were found. In each case a series of nickel–iron–carbon alloys of gradually increasing iron content was prepared and these elements were then added to each alloy. Since calcium and magnesium are potent desulphurizing elements when added to nickel–carbon alloys, and since they readily dissolve in these alloys, it was argued that the element required for the treatment of iron-rich alloys should be a desulphurizer, a carbide-stabilizer, and also capable of dissolving easily in the melt. These experiments were all carried out in graphite crucibles in which were melted the appropriate amounts of nickel and iron. In every case the weight of the resulting ingot was between 50 and 100 g. Melting in this manner automatically gives hypereutectic alloys.

After many trials an element was found which gave spherulitic nodular structures when added to nickel–carbon and nickel–iron–carbon alloys containing more than 50% of iron. The element having this effect was cerium and it was found to be possible to produce spherulitic graphite structures in pure nickel–carbon, iron–nickel–carbon and in pure iron–carbon alloys when they were prepared by melting in graphite crucibles and treating in the molten condition by this element.

No useful purpose would be served by describing all the experiments carried out in this manner,

Table I

CERIUM-TREATED, HYPEREUTECTIC IRON–NICKEL–CARBON ALLOYS

Ingot No.	Weight of Ingot, g.	Ni, %	Ce Added, %
1	99·3	19·40	0·6
2	58·6	4·78	0·6
3	59·6	0·005	0·2

but many of the ingots had interesting microstructural features which can be conveniently illustrated by considering three examples, details of which are given in Table I.

Ingots Nos. 1 and 2 were made up of pure nickel and high purity electrolytic iron, and ingot No. 3 was made up entirely of electrolytic iron. These charges were melted in small graphite crucibles in a platinum-wound tube furnace. The molten alloys were each held at 1500° C. for 15 min. before the cerium addition was made. The cerium was in the form of the pure metal, and after dropping on to the surface of the molten metal it was stirred in with a thin silica rod. The ingots were allowed to cool slowly and to solidify in the furnace, the rate of cooling being approximately 10° C./min. The sulphur contents of these alloys were below 0·001%.

Ingot No. 1, with 19·40% of nickel, had uniformly distributed nodules in the lower two-thirds of the sample, but considerable segregation of hypereutectic graphite by flotation had occurred in the top third. The general structure of the lower portion is shown in Fig. 1. In addition to the graphite nodules, a few areas of interdendritic graphite can be seen. This graphite is very similar to that illustrated in a previous paper[1] (*see* ref., Figs. 85, 86, and 92) and is probably formed as the result of carbide decomposition at a very low temperature, when the ability of the graphite to diffuse is limited. In the previous paper this interdendritic graphite had been obtained

by the quenching of nickel–carbon and nickel–iron–carbon alloys. It is interesting to observe that cerium additions have effects upon the graphite structure resembling those of rapid cooling. At the top of this ingot the hyper-eutectic graphite was in two principal forms: some was in the form of star-shaped aggregates, or imperfect spherulites, and some apparently in the form of completely isolated graphite crystallites. The general structure of this upper region is illustrated at a relatively low magnification in Fig. 2. At a high magnification the star-shaped aggregates appear to be imperfectly formed spherulites. A typical example of this structure is shown at a high magnification in Fig. 3. These aggregates only occurred in the upper part of the ingot, where hyper-eutectic graphite had segregated, so it is reasonable to suppose them to be the hyper-eutectic graphite. The graphite crystallites in these spherulitic aggregates have the same orientation as those of perfect spherulites, *i.e.*, their basal planes are oriented at right angles to the direction of growth. (This can be demonstrated by the use of the polarizing microscope.) Graphite spherulites formed by the annealing of high sulphur white iron appear to grow by the simultaneous crystallization, with equal speed, of fibres radiating from a common centre in all directions. Such a mechanism would lead to a spherical shape at every moment during growth. Morse and Donnay,[5] in agreement with certain German investigators, have advanced the hypothesis in connection with the crystallization of inorganic salts, that spherulitic crystallization may also begin from a centre within two opposite solid angles and that at a further stage outward growth of the fibres ceases and further crystallization takes place by filling-in the "waist." Perhaps the case illustrated in Fig. 3 represents the early stage of spherulitic crystallization of this type before the "waist" has begun to fill in. On the other hand, it must be remembered that these aggregates have floated to the top of the ingot, during which process normal crystallization may have been interrupted.

The apparently isolated graphite crystallites in the top of ingot No. 1 had several interesting features. They varied in shape from squat to elongated, almost lamellar, crystals and usually had a rim of differently oriented graphite. The elongated crystals could at first sight be mistaken for normal flakes of graphite, but examination under polarized light showed them to be oriented differently. A typical example of such an elongated graphite crystal is shown in Fig. 4 (*a*) under plane-polarized light. The main crystal is here in its position of maximum pleochroic absorption and hence it appears dark, but the outer rim of graphite is in its position of minimum pleochroic absorption, and so it appears light. The direction of the plane of polarization of the incident light in this micrograph (and also in Figs. 4*b*, 5*a*, and 5*b*) is north–south. Figure 4 (*b*) shows a normal flake of hyper-eutectic graphite in an untreated pure iron–carbon alloy photographed under the same conditions, but in this case the crystallite is in its position of minimum pleochroic absorption[6] and so it appears light. Figures 5 (*a*) and 5 (*b*) show the appearance of these two specimens after rotation through 90° when their respective absorptions are reversed. Quite obviously these elongated crytals in the treated ingot have their basal planes oriented at right angles to those of normal graphite flakes. Now in normal graphite flakes the basal planes of the graphite are oriented parallel to the long dimension[1] and, therefore, in the case illustrated in Figs. 4 (*a*) and 5 (*a*) the basal planes of the graphite must be oriented at right angles to the long dimension. The crystallites of graphite spherulites also have this orientation[1] so that the individual crystallites in ingot No. 1 may represent the remnants of broken spherulites or spherulitic aggregates previously illustrated in Fig. 3. The outer rim of graphite in Figs. 4 (*a*) and 5 (*a*) is oriented at right angles to the main crystal. It is suggested that this graphite represents eutectic graphite deposited on the hyper-eutectic crystal. Why this orientation difference between the eutectic and the hyper-eutectic graphite should exist is not known and it becomes more difficult to understand when later in this paper graphite, arising from the decomposition of "eutectic" carbide, is shown to be similarly oriented to the hyper-eutectic spherulites upon which it is deposited.

Ingot No. 2 had a similar segregation of hyper-eutectic graphite at the top of the sample, and the lower portion of the melt had apparently normal spherulitic graphite when examined at low magnifiation. This structure is shown in Fig. 6. At high magnification, however, most of these nodules were found to be duplex spherulites consisting of a fine-grained central spherulitic nucleus with a peripheral layer of coarser-grained graphite, a considerable amount of metal being trapped between the two. A typical example of this duplex spherulitic structure is shown in Fig. 7. The reason for this double structure is not easily explained. Later in this paper similar duplex structures are shown in cast irons, but the graphite crystallites in the peripheral layer are continuous with those of the core. It is possible that the central core is a hyper-eutectic spherulite and the peripheral layer is eutectic graphite, but if this were the case one might expect a larger number of such aggregates near the top of the ingot and this was not found to be so. The hyper-eutectic graphite at the top of the ingot was in two forms: some existed as imperfectly formed spherulites as shown in Fig. 8, and some as slightly dispersed aggregation in which a radial structure could be faintly detected. A typical example of this latter form of graphite is shown in Fig. 9. It would almost seem that there is a force of attraction between the individual graphite particles, and the structure as a whole shows a marked resemblance to some of the "flake-aggregate" nodules which can be obtained by the annealing of white iron in which all the sulphur exists as manganese sulphide.[3,4]

Ingot No. 3 had the general structure shown in Fig. 10, consisting of relatively small normal spherulites with numerous large masses of graphite which became more abundant towards the top of the ingot, indicating them to be the hyper-eutectic graphite. At high magnifications these large masses of graphite are seen to be random aggregations of small graphite crystallites, as illustrated in Fig. 11.

Similar experiments to those illustrated above

were also carried out with alloys to which an addition of sulphur had been made before the cerium was added. In none of these cases did a nodular structure result, and so the next group of experiments on a larger scale was carried out with relatively low sulphur materials.

In the experiments discussed so far, pure cerium had been used, but owing to the high cost of this addition further experiments were carried out with commercial *mischmetall*, which provided a much cheaper and convenient source of cerium. The *mischmetall* used by the present investigators has been found to have a composition lying within the following limits, depending upon its source :

Cerium	45–52%
Other Rare Earths ...	45–48%
Iron	0·5–2·5%
Magnesium	Up to 1·6%
Silicon, aluminium, and calcium ...	Up to 0·3%

The magnesium found in *mischmetall* is usually a deliberate addition by the manufacturers and all the results quoted in this report have been obtained with magnesium-free *mischmetall*. It was found preferable to avoid magnesium because when *mischmetall* containing this element is added to cast iron the magnesium volatilizes and burns, causing the oxidation of the remainder of the addition. The investigators have satisfied themselves in the course of their work that for the production of nodular structures cerium is the important element in *mischmetall*, the other rare earths present playing no appreciable part. All the analytical figures quoted represent actual cerium contents and not total rare earths, and in general the effects observed follow closely upon the cerium contents quoted.

INFLUENCE OF CERIUM IN CAST IRON—GENERAL

The influence of cerium in cast iron has been investigated and discussed on several occasions,[7–18] but in many ways the information available is confusing. Nevertheless, two important points are common to the conclusions of several investigators, namely, that cerium can be a potent carbide stabilizer and also an effective desulphurizer. All the investigaors used *mischmetall* for making the cerium additions and very varied yields of cerium have resulted. Baukloh and Meierling,[17] for instance, added *mischmetall* to cupola-melted metal and obtained extensive desulphurization, depending upon the amount added. They did not record a carbide-stabilizing influence, even though they added as much as 2% of *mischmetall*. They did find, however, an improvement in mechanical properties with increasing additions, which appeared to be due to a refining effect of the cerium upon the graphite structure. On the other hand, Bastien and Guillet[14] added *mischmetall* to very low sulphur cast iron melted in an electric furnace and, when the addition was made under conditions where the cerium was not lost by oxidation, a pronounced carbide-stabilizing influence was noted. Summarizing all the previous work, it can be said that when cerium has been added to high sulphur cast iron, a desulphurizing effect accompanied by an improvement in mechanical properties and a graphite refinement has resulted. However, when the addition has been made to low sulphur metal, a pronounced carbide-stabilizing effect has been detected.

No previous investigators have suggested the use of cerium additions for the production of nodular graphite structures in cast irons.

DETERMINATION OF CONDITIONS UNDER WHICH CERIUM WILL PRODUCE NODULAR STRUCTURES IN CAST IRON

Having established that cerium additions would cause the formation of nodular graphite structures in hyper-eutectic iron-rich alloys prepared from pure materials, attention was concentrated upon the use of these additions to give nodular structures in cast irons. For these experiments crucible melts of between 50 and 300 lb. and electric-arc-furnace melts of up to 100 lb. were used. At first, melts were made up of hematite pig iron and steel scrap to give compositions within the range :

Total C, %	Si, %	Mn, %	P, %	S, %
3·0–3·2	1·0–2·3	0·4–1·0	0·03–0·06	0·02–0·04

It was found that even very small additions of cerium to compositions lying within this range caused the irons to solidify white over a wide range of section sizes, but occasionally when mottled structures were obtained a few spherulitic graphite nodules could be seen in the structure. For instance, a melt of hematite and steel scrap was carried out in an indirect arc furnace. Fifty pounds of the metal were tapped off and treated in the ladle with 60 g. of *mischmetall*, the metal temperature at the time of the addition being 1420° C. The treated metal was cast into 1·2 in. dia. test-bars which gave mottled fractures. Analysis of the test-bars gave the following composition :

Total C, %	Si, %	Mn, %	S, %	P, %	Ce, %
3·00	2·29	0·88	0·10	0·031	0·043

Metallographic examination of these test-bars revealed them to have typical hypo-eutectic white-iron structures with occasional patches of nodular graphite. A typical example of this structure is shown in Fig. 12, which shows a few nodules of graphite in a matrix of pearlite together with some massive eutectic carbide.

Experiments of this type indicated that additions of cerium to cast irons would give nodular graphite structures, but the carbide-stabilizing influence of cerium was too great to permit adequate carbide decomposition in normal hypo-eutectic cast irons. In an attempt to overcome this difficulty, trials were made using irons of much higher silicon content (*i.e.*, of the order of 4–5%) in the hope that such irons would graphitize more readily. Again, it was found that nodular structures could be produced, but such treated irons were very susceptible to chilling, the amount of addition needed to produce the required structure being very critical. An example of the type of nodular structure obtained in such high silicon iron is shown in Fig. 13. This was taken

from a 1·2-in. dia. test-bar, cast from a melt of hematite, steel scrap, and ferrosilicon carried out in an indirect arc furnace. In this case 20 lb. of the molten metal were treated with 20 g. of *mischmetall* before casting, the metal temperature at the time of treatment being 1380° C. The analysis of this bar was :

Total C, %	Si, %	Mn, %	S, %	P, %	Ce, %
2·44	4·01	0·82	0·015	0·036	0·034

A similar ladle of metal from the same melt, treated with 12 g. of *mischmetall*, gave 1·2-in. dia. test-bars having normal undercooled-graphite structures, whereas another ladle treated with 30 g. of *mischmetall* gave white-iron structures in bars of the same size. The nodular structures obtained in irons of this composition were not perfect, nor were they uniformly distributed, and usually there were long streaks of graphite, apparently surrounding the primary dendrites, which rendered the material very weak and brittle. This type of graphite formation is illustrated in Fig. 14. Occasionally irons were obtained, by treatment with cerium, which appeared to have undercooled-graphite structures, but examination at high powers revealed the graphite to differ from normal undercooled graphite. A typical example of this structure is illustrated in Fig. 15. The graphite is seen to be arranged in striæ, in a fine mesh-like pattern, and also as a continuous film surrounding the primary dendrites. The composition of this iron was :

Total C, %	Si, %	Mn, %	S, %	P, %	Ce, %
2·35	4·67	0·60	0·017	0·023	0·055

It would appear from this micrograph that the graphite has formed as a result of the decomposition of the acicular white-iron eutectic which has been reported previously.[1,2] In the same sample, areas could be found where some aggregation of the graphite had occurred to give small nodules. This is illustrated in Fig. 16.

At this stage it was realized that the production of nodular graphite structures in cast iron by the use of cerium would require the provision of nuclei for the crystallization of graphite arising from the decomposition of eutectic carbide after solidification. In the preliminary experiments (reported in the previous section) good nodular structures were obtained in cerium-treated hyper-eutectic alloys, both the hyper-eutectic and eutectic graphite being obtained in the spherulitic form. There was also some evidence that the hyper-eutectic nodules formed before the eutectic solidified. It was therefore decided to investigate the influence of cerium additions on hyper-eutectic grey cast irons, it being thought that the hyper-eutectic graphite would serve to nucleate and thus facilitate the decomposition of the eutectic. This approach proved completely successful and it was possible to determine the limits of composition within which an iron would have a nodular structure in the as-cast state if treated in the molten condition with the appropriate amount of cerium. It was quickly found that such irons treated with cerium to give nodular structures have mechanical properties superior to those of the untreated material and usually higher in many respects than those of accepted high-duty grey cast irons. Grey, or substantially grey cast irons in which all or part of the graphitic carbon content is in the form of nodules or spherulites visible under the microscope, and which have not been subjected to a heat-treatment process for the purpose of producing that graphite structure, will be referred to as " nodular cast irons."

COMPOSITION REQUIREMENTS FOR THE PRODUCTION OF NODULAR CAST IRONS

Considerable effort has been devoted to determining the limits of composition within which an iron would have a nodular graphite structure if treated with an appropriate amount of cerium. It is not possible in this paper to describe all the experimental work which has been involved, but these limits are stated below as concisely as possible. As has been shown earlier in this report, nodular structures can be obtained with compositions lying outside these limits, but the following are meant to indicate practical limits within which the process can be operated easily with a reasonable guarantee of success. The reasons for some of the less obvious composition requirements will be dealt with later in this paper.

1. The iron to be treated must solidify grey in the untreated condition ; the process cannot be applied to a white iron. With this reservation, the matrix structure may be pearlitic, ferritic, a mixture of ferrite and pearlite, martensitic, acicular, or austenitic.

2. In irons containing less than 10% of nickel (nickel need not be present) a high carbon content is necessary and the iron to be treated should be hyper-eutectic, that is, it must have a carbon content in excess of that given by the formula :

$$4{\cdot}3 - \tfrac{1}{3}[\mathrm{Si}(\%) + \mathrm{P}(\%)]$$

3. The silicon content of the iron to be treated should preferably be in excess of 2·3%, and may be as high as 7% without influencing the essential features of the process. With the special-purpose irons having 10–15% of silicon, only the hyper-eutectic graphite can be obtained with certainty in the nodular form.

4. Any deficiency of silicon may be compensated by the presence of nickel and/or copper in appropriate amounts. In this respect 3% of nickel and/or copper are to be considered as equivalent to 1% of silicon. Alternatively, a deficiency of silicon may be compensated for by the addition of ferrosilicon or similar material to the molten metal.

5. The manganese content of the metal may have any value, providing the other conditions listed here, particularly No. 1, are met.

6. The sulphur content of the molten metal to which the cerium addition is to be made must be as low as possible, and it is not practicable to treat metal with sulphur contents in excess of 0·06%. One of the functions of the cerium addition is to reduce the sulphur content of the treated metal to a value usually below 0·015%, and sometimes values as low as 0·005% are achieved.

7. The phosphorus content should not exceed 0·5% and should preferably be below 0·1%.

Table II

INFLUENCE OF CERIUM ADDITION ON MECHANICAL PROPERTIES OF REMELTED HEMATITE

Diameter of Test Bars, in.	Transverse Rupture Stress, tons/sq. in.		Deflection, in.		Tensile Strength, tons/sq. in.		Brinell Hardness No.		Impact Strength, ft. lb.	
	Without Cerium	With Cerium	Without Cerium	With Cerium	Without Cerium	With Cerium	Without Cerium	With Cerium	Without Cerium	With Cerium
2·1	21·2	34·5	0·23	0·25	9·3	18·3	153	164	—	—
1·2	24·8	43·8	0·29	0·50	13·0	21·4	163	185	—	—
0·875	29·4	48·7	0·19	0·32	15·5	22·2	185	195	13	45
0·6	33·9	62·4	0·16	0·30	18·5	29·0	202	231	—	—

8. The elements copper and nickel may be present in any amount without influence.

9. The elements chromium, molybdenum, and vanadium may be present in any amount, providing the other conditions listed above are observed.

10. Titanium present in amounts characteristic of British pig irons exerts no effect.

A study of the literature upon the influence of cerium in cast iron shows that previous investigators failed to obtain nodular structures because they added too much and obtained white-iron structures, or the irons were white before treatment, or the sulphur contents of the irons being treated were too high, or the irons were not hyper-eutectic, or the cerium yield was poor due to the method of making the addition. In some cases several of these factors were combined. For instance, Baukloh and Meierling[17] treated high sulphur hypo-eutectic irons, and Bastien and Guillet[14] treated low sulphur hypo-eutectic irons, in some instances adding sufficient cerium to obtain white irons and in others achieving only a very poor yield of cerium.

PRELIMINARY ILLUSTRATIVE EXAMPLES OF THE PRODUCTION OF NODULAR IRONS BY THE ADDITION OF CERIUM TO THE MOLTEN METAL

As will be described later, the process has been developed beyond the stage of simple additions of cerium to the molten metal, but before these variations in the procedure are dealt with it is convenient to give a few examples to illustrate the types of microstructure which are obtained and the levels of mechanical properties which can be achieved by the use of cerium alone as an addition. The transverse, deflection, and tensile figures given in this paper for 2·1, 1·6, 1·2, 0·875 and 0·6-in. dia. bars were obtained on bars cast and tested according to B.S.I. Specification 786/1938; the impact figures were obtained on bars tested according to B.S.I. Specification 1349/1947; the 3-in. dia. bars were tested in transverse on 18-in. centres; the as-cast shaped tensile bars had the dimensions given in B.S.I. Specification 310/1947.

EXAMPLE NO. 1—ADDITION OF CERIUM TO REMELTED HEMATITE PIG IRON

Fifty pounds of a hematite pig iron of the following analysis :

Total C, %	Si, %	Mn, %	S, %	P, %
4·02	2·60	0·63	0·14	0·028

were melted in a crucible furnace and cast, at a temperature of 1350° C., into test-bars of four different sizes. A further similar melt was carried out, but in this case 50 g. of *mischmetall* were added to the molten metal and stirred in before casting. The two sets of bars gave the following chemical analyses :

	Total C, %	Si, %	Mn, %	S, %	P, %	Ce, %
(*a*)	3·85	2·47	0·55	0·015	0·024	—
(*b*)	3·83	2·45	0·53	0·10	0·023	0·046

(*a*) Remelted pig iron

(*b*) Remelted pig iron with cerium addition

The mechanical properties of these two sets of bars are given in Table II.

The treated bars have a consistently higher level of mechanical properties than the untreated.

The microstructures of all the untreated bars had mixtures of flake and undercooled graphite in a matrix of pearlite and ferrite (Fig. 17). The microstructures of the treated bars were quite different from those of the untreated material, showing well-developed spherulites of hyper-eutectic, together with a new form of graphite somewhat resembling flake graphite but quite different in appearance from that in the untreated bars. The microstructures of the treated 0·6, 1·2, and 2·1-in. dia. bars are shown in Figs. 18, 19, and 20 respectively. The matrix in each case consists of ferrite and pearlite, the amount of ferrite increasing with increasing section size. The hyper-eutectic spherulites can be clearly seen. The flake-like character of the "eutectic" graphite increases with increasing section size. That this graphite differs from normal flake graphite may not be immediately apparent, but the difference will be made more clear in the further examples which are given in what follows. To distinguish it from normal flake graphite it will be referred to subsequently in this paper as "quasi-flake graphite." At high magnifications it frequently has the appearance of being an aggregate of small graphite nodules. A typical example of this quasi-flake graphite is shown in Fig. 21 at a higher magnification.

The hyper-eutectic nodules found in irons of this type treated with cerium usually have perfect spherulitic structures exactly similar to those illustrated previously for high sulphur malleable cast iron[3,4] and for nickel–carbon alloys ;[1] each nodule consisting of radially arranged graphite crystallites with their basal planes at right angles to the radii of the spheroid.

Table III

INFLUENCE OF CERIUM CONTENT ON MECHANICAL PROPERTIES OF 3-IN. DIA. BARS

Bar No.	Transverse Rupture Stress, tons/sq. in.*	Deflection, in.*	Tensile Strength, tons/sq in.	Brinell Hardness No.	Cerium, %
1	13·6	0·21	6·7	98	Nil
2	38·0	0·21	17·9	167	0·040
3	46·5	0·35	22·4	176	0·053
4	47·6	0·34	24·0	181	0·072
5	50·8	0·42	26·3	179	0·101

* Tested on 18-in. centres

Frequently, however, these spherulites are duplex in structure, having a spherulitic central nucleus with similarly crystallized graphite in a uniform layer around the nucleus. A typical nodule with this structure is shown in Fig. 22 at a high magnification. This micrograph was taken under plane-polarized light with normal vertical illumination. Figure 23 shows the same nodule under polarized light between crossed nicols. The two regions of this nodule can be clearly differentiated and the crystallites in the outer layer have the same orientation as the crystallites of the nucleus to which they are attached. This structure is very similar to that which was found in the cerium-treated hyper-eutectic pure iron–nickel–carbon alloy and illustrated in Fig. 7. In the case of the treated cast iron, the crystals in the peripheral layer appear to be of the same order of size as those of the nucleus, whereas the peripheral crystallites in the pure ternary alloy were coarser than those of the nucleus. It is suggested that spherulites in the treated cast irons consist of nucleus spherulites of hyper-eutectic graphite with peripheral layers of " eutectic " graphite. This would imply that the hyper-eutectic spherulites exist before the " eutectic " carbide decomposes and so nucleate the graphitization reaction during and after solidification. In Figs. 18, 19, and 20 no quasi-flake graphite exists in the immediate vicinity of the hyper-eutectic nodules. Further evidence will be introduced later to support this contention. No spherulitic aggregates such as were found in the pure alloy referred to above have been found in treated cast irons.

EXAMPLE NO. 2—INFLUENCE OF CERIUM CONTENT

The amount of cerium which can be added to a low sulphur cast iron without causing it to solidify white depends upon the section size into which it is cast ; the larger the section size the greater the amount of cerium which can be added. For this reason the influence of increasing amounts of cerium upon the graphite structure can best be observed in large, slowly cooled sections where the tendency to solidify white is not marked.

To illustrate the effect of increasing additions of cerium, 270 lb. of pig iron of the following composition were melted in an oil-fired crucible furnace :

Total C, %	Si, %	Mn, %	S, %	P, %
3·79	2·80	0·53	0·028	0·015

Two test-bars, each 21 in. long and 3 in. in diameter, were cast in green-sand moulds. For this, five ladles of metal, each weighing 50 lb., were taken from the furnace. No addition was made to the metal in the first ladle, but increasing amounts of *mischmetall* were added to the metal in the remaining four ladles. The actual additions were :

Tap 1 No addition
Tap 2 50 g. of *mischmetall*
Tap 3 65 g. of *mischmetall*
Tap 4 90 g. of *mischmetall*
Tap 5 100 g. of *mischmetall*

The mechanical properties and cerium contents (as found by analysis) of these bars are given in Table III.

All the mechanical properties show a progressive improvement with increasing cerium content. The reason for this is clear from the microstructures. The untreated bar No. 1 had a structure of coarse flake graphite in a matrix of ferrite with some pearlite. This is illustrated in Fig. 24. Bar No. 2 had a few hyper-eutectic graphite spherulites with coarse quasi-flake graphite, but with increasing amounts of cerium in bars 3, 4, and 5 this graphite becomes less flake-like and more nodular in appearance. Fig. 25 shows the general structure of bar No. 2, and Fig. 26 the general structure of bar No. 5. The influence of increasing cerium content is clearly seen.

EXAMPLE NO. 3—INFLUENCE OF CERIUM IN AN AUSTENITIC IRON

In item 2 of the composition limits set out in the previous section of this paper it was said that for the production of nodular structures with cerium, irons containing more than 10% of nickel need not be hyper-eutectic according to the formula :

$$\text{Eutectic carbon content} = 4{\cdot}3 - \tfrac{1}{3}[\text{Si}(\%) + \text{P}(\%)]$$

This statement, of course, ignores the influence of nickel on the eutectic carbon content. Nickel lowers this value, but in the opinion of the present authors the precise effect of this element, in conjunction with silicon, upon the eutectic carbon concentration is not known sufficiently to be expressed in terms of a comprehensive formula. It is possible, therefore, that some irons containing nickel which have been studied by the present investigators have, in fact, been hyper-eutectic, although not apparently so from the formula given above. Neverthless, there has been accumulated a fair amount of evidence to indicate that when the nickel content of cast irons exceeds about 10%, hypo-eutectic irons respond to

Table IV

INFLUENCE OF CERIUM ON TENSILE STRENGTH OF AN AUSTENITIC IRON

Tap No.	Tensile Strength, tons/sq. in.	Cerium, %
1	8·2	Nil
2	8·5	0·009
3	16·3	0·031
4	22·5	0·046
5	26·0	0·058

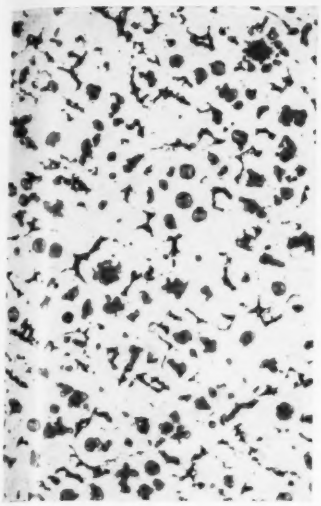

Fig. 1—General structure of lower portion of cerium-treated ingot with 19·40% of Ni. Unetched × 60

Fig. 2—General structure of upper portion of cerium-treated ingot with 19·40% of Ni. Unetched × 150

Fig. 3—Imperfectly formed hypereutectic spherulite in upper zone of cerium-treated ingot with 19·40% of Ni. Unetched × 1000

Fig. 4—(a) Graphite crystallite from cerium-treated ingot with 19·40% of Ni. (b) Hypereutectic graphite flake in pure iron-carbon alloy. Both under plane-polarized light. Unetched × 1200

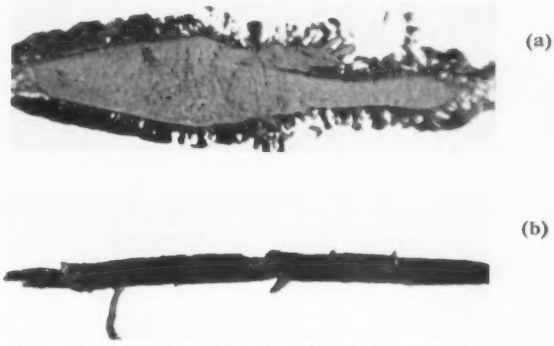

Fig. 5—(a) Same as Fig. 4(a), but after rotation through 90°. (b) Same as Fig. 4(b), but after rotation through 90°

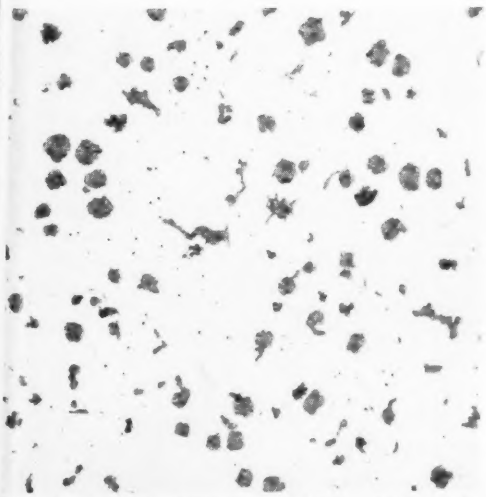

Fig. 6—General structure of lower portion of cerium-treated ingot with 4·78% of Ni. Unetched × 60

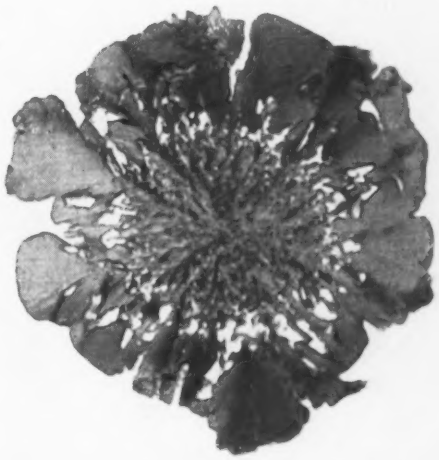

Fig. 7—Duplex spherulite in cerium-treated ingot containing 4·78% of Ni. Unetched × 1000

[*Morrogh and Williams*

[*To face p. 312*

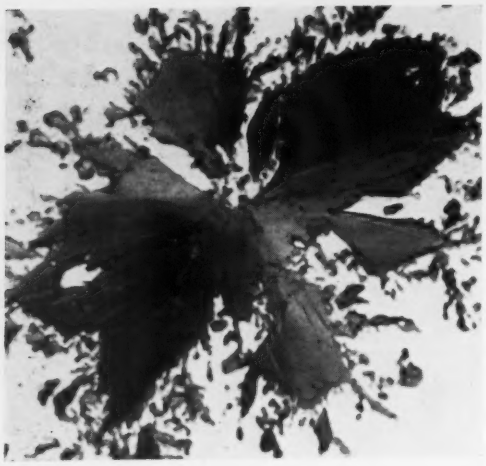

Fig. 8—Imperfectly formed hyper-eutectic graphite spherulite in cerium-treated ingot with 4·78% of Ni. Unetched × 1000

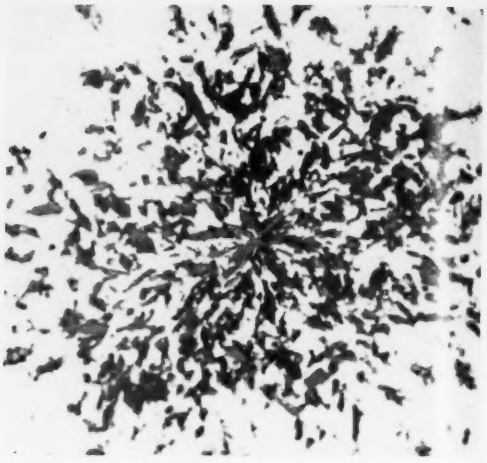

Fig. 9—Dispersed form of " nodule " in cerium-treated ingot with 4·78% of Ni. Unetched × 1000

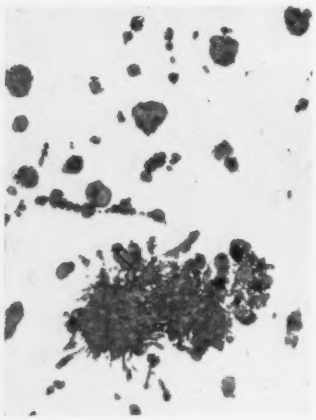

Fig. 10—General structure of cerium-treated pure iron-carbon ingot. Unetched × 100

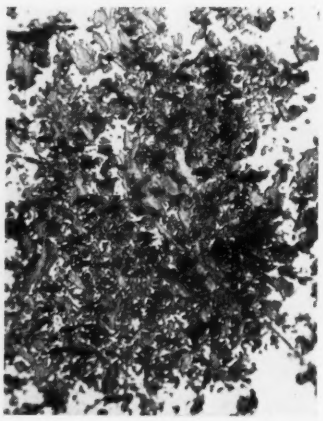

Fig. 11—Random aggregate of graphite in cerium-treated pure iron-carbon ingot. Unetched × 400

Fig. 12—Cerium-treated hypo-eutectic cast iron. Etched in picric acid × 300

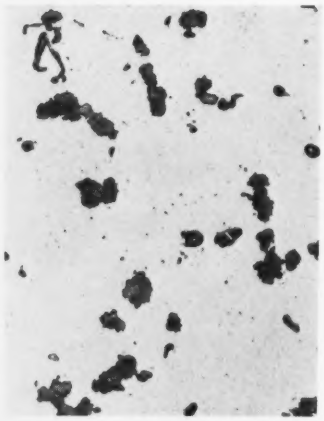

Fig. 13—Nodular graphite in cerium-treated hypo-eutectic iron with 4·01% of silicon. Unetched × 300

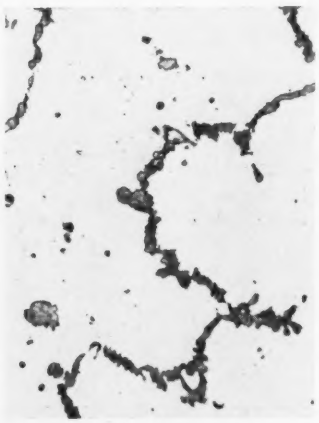

Fig. 14—Interdendritic streaks of graphite in cerium-treated hypo-eutectic iron with 4·01% of Si. Unetched × 300

Fig. 15—Graphite structure in cerium-treated hypo-eutectic iron with 4·67% of Si. Unetched × 600

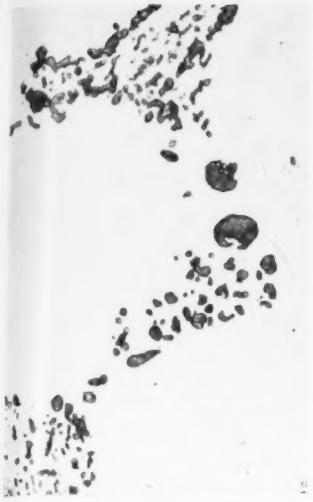

Fig. 16—Partial aggregation of spherulites in cerium-treated hypo-eutectic iron with 4·67% of Si. Unetched × 600

Fig. 17—General structure of untreated 1·2-in. bar. Remelted hematite. Etched in picric acid ×60

Fig. 18—General structure of 0·6-in. bar. Cerium-treated nodular iron × 60

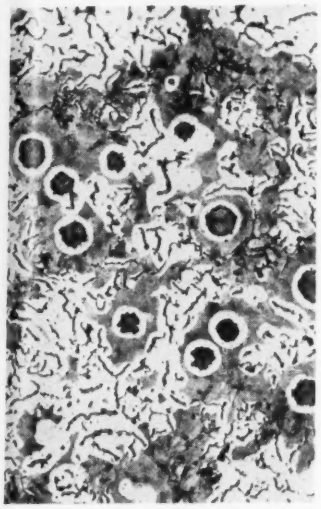

Fig. 19—General structure of 1·2-in. bar of cerium-treated nodular iron. Etched in picric acid × 60

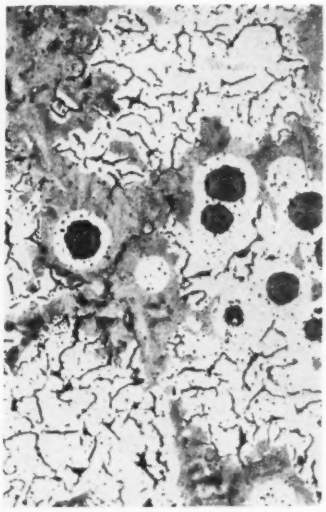

Fig. 20—General structure of 2·1-in. bar of cerium-treated nodular iron. Etched in picric acid × 60

Fig. 21—Quasi-flake graphite in cerium-treated nodular iron. Unetched × 1000

Fig. 22—Duplex hyper-eutectic spherulite. Plane-polarized light. Unetched × 1500

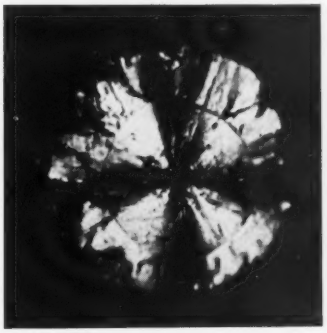

Fig. 23—Same as Fig. 22, but between crossed nicols. Unetched × 1500

[*Morrogh and Williams*

Fig. 24—Untreated remelted hematite pig, cast in 3-in. bar. Etched in picric acid × 60

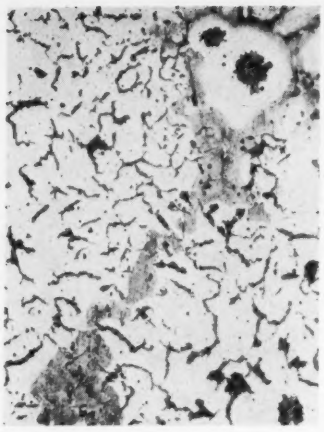

Fig. 25—Remelted hematite with 0·040% of Ce, cast in 3-in. bar. Etched in picric acid ×60

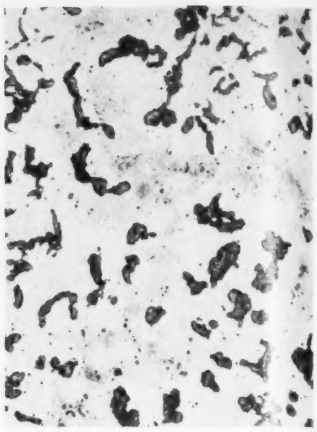

Fig. 26—Remelted hematite with 0·101% of Ce, cast in 3-in. bar. Etched in picric acid 60

Fig. 27—Normal flake graphite in untreated austenitic iron. Unetched × 100

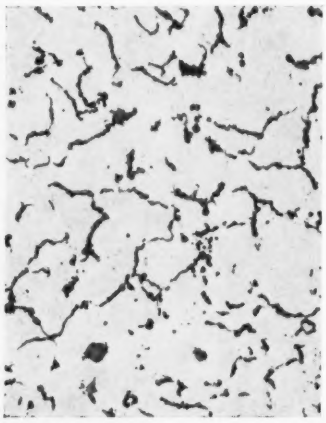

Fig. 28—Quasi-flake graphite in austenitic iron with 0·031% of Ce. Unetched × 100

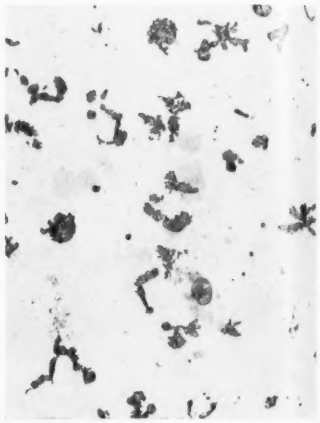

Fig. 29—Nodular graphite in austenitic iron with 0·058% of Ce. Unetched × 100

Fig. 30—General structure of cerium-treated high sulphur iron. Etched in picric acid × 60

Fig. 31—Segregation of MnS with hyper-eutectic graphite in cerium-treated high sulphur iron. Unetched × 600

Fig. 32—Manganese sulphide with duplex structure in cerium-treated high sulphur iron. Unetched × 1250

the cerium treatment to give nodular structures. (It will be recalled from the earlier work[1] that hypo-eutectic pure nickel–carbon alloys could be obtained with nodular structures by treatment with calcium silicide.)

Austenitic cast irons usually, but not necessarily, contain at least 10% of nickel, together with other alloying elements, and so considerable interest attaches to the modification of the graphite structure in such highly alloyed materials.

An austenitic cast iron of the following composition was melted in an indirect arc furnace :

Total C, %	Si, %	Mn, %	S, %	P, %	Ni, %	Cu, %
2·92	2·51	0·51	0·20	0·040	12·79	6·61

Five taps, each of 20 lb. were taken from this melt and treated as follows :

Tap 1	No addition
Tap 2	5 g. of *mischmetall*
Tap 3	10 g. of *mischmetall*
Tap 4	15 g. of *mischmetall*
Tap 5	25 g. of *mischmetall*

From each tap a number of shaped tensile bars having a gauge-length diameter of 0·564 in. were cast. These bars were tested without machining. The average tensile strengths and the cerium contents of these bars are given in Table IV.

Again we have a progressive increase in tensile strength with increasing cerium content. The reasons for this are clear from the microstructures. The bars from tap No. 1 all had coarse flake-graphite structures (Fig. 27). The bars from tap No. 2 had coarse flake graphite with a little undercooled graphite, but the bars from tap No. 3 had the quasi-flake graphite structure (Fig. 28). If Fig. 27 is compared with Fig. 28, the difference between normal and quasi-flake graphite can be readily appreciated. Structures with this form of graphite are found to be mechanically stronger than those with normal flake graphite and hence the tensile strengths of the bars from tap No. 3 are nearly twice those of the bars from taps Nos. 1 and 2. The bars from tap No. 4 had a mixture of nodular and quasi-flake graphite and the bars from tap No. 5 were almost completely nodular. The structure of one of the bars from tap No. 5. is shown in Fig. 29. The metallic matrix in the bars cast from this melt was entirely austenitic in each case.

The three examples which have now been given demonstrate the types of graphite structure which can be produced by the addition of cerium to low sulphur hyper-eutectic grey cast irons and to austenitic cast irons highly alloyed with nickel. The hyper-eutectic graphite is readily obtained in perfect spherulites and the eutectic graphite in the form of quasi-flake graphite which tends to assume a nodular form with increasing amounts of cerium. The reason for this latter effect of cerium is not very clear. It may be that with larger proportions the " eutectic " carbide is stabilized so that it decomposes at a lower temperature, under which condition the graphite tends to be nodular rather than of the quasi-flake variety. On the other hand, increasing amounts of cerium may increase the degree of nucleation either by providing more hyper-eutectic graphite spherulites or by providing nuclei directly related to cerium or cerium compounds.

INFLUENCE OF SULPHUR UPON THE PRODUCTION OF NODULAR STRUCTURES BY CERIUM ADDITIONS

In item 3 of the section on composition requirements, reference has been made to the necessity of a low sulphur content in the metal to be treated with cerium in order to obtain nodular structures. One of the necessary reactions involved in this process is the removal of sulphur from the molten metal by the cerium addition. The desulphurizing effect of cerium has been well established by Baukloh and Meierling,[17] who made additions of *mischmetall* to cupola-melted metal in the ladle. These investigators reported a graphite-refining effect with increasing additions of *mischmetall* and, starting with a sulphur content of 0·121% they were able to reduce this figure to 0·010% by the addition of 2% of *mischmetall*. All of the irons treated by these investigators were hypo-eutectic and it seems, in the light of the experience of the present investigators, that the whole of the cerium additions used by them was involved in the desulphurizing reaction. Their micrographs all showed normal flake graphite structures.

When pure cerium, or any cerium alloy such as *mischmetall*, is added to molten cast iron a sulphur-rich cerium compound immediately forms on the surface of the molten metal. Baukloh and Meierling have suggested that this sulphur elimination may be represented by the following equations :

$$3FeS + 2Ce = 3Fe + Ce_2S_3, \text{ and}$$
$$Ce_2S_3 + 5O_2 = 2CeO_2 + 3SO_2$$

It has been found by the present investigators that the sulphur content of the iron must be reduced, by the cerium addition, to a value not greater than about 0·015% if nodular graphite structures are to be produced. When this low sulphur content has been achieved any cerium present in excess of that combined with the sulphur dissolves as cerium in the metallic phases, exerts a carbide-stabilizing influence, and functions to produce nodular graphite.

Desulphurization by cerium appears to be a case of segregation desulphurization ; the cerium–sulphur compound formed being relatively insoluble in molten cast iron. The flotation of a cerium–sulphur compound in molten cast iron was demonstrated in the following manner. A high sulphur pig iron was treated in the molten condition with *mischmetall* and a 3-in. dia. test-bar, 21 in. long, was immediately cast, top-run in a green-sand mould. The metal temperature at the time of treatment was 1420° C., and at the time of pouring, 1385° C. A bar cast in such a manner would remain molten in the mould for sufficient time to allow any segregation effects to be manifest. After cooling, the bar was cut transversely into seventeen sections numbering 1, at the bottom, to 17, at the top. These sections were subjected to chemical analysis, the results of which are given in Table V.

The simultaneous segregation of sulphur and cerium towards the top of the bar is clearly indicated. No doubt the upward flotation of the cerium–sulphur compound was arrested by solidification, and if the sample could have been held in the molten condition

Table V

SEGREGATION OF SULPHUR AND CERIUM IN CERIUM-TREATED HIGH SULPHUR IRON

Section No.	Position	Total C, %	Si, %	P, %	Mn, %	S, %	Ce, %
1	Bottom	3·67	2·72	0·031	0·51	0·058	0·007
2		,,	,,	,,	0·51	0·058	0·010
3		,,	,,	,,	0·51	0·060	0·005
4		,,	,,	,,	0·51	0·060	0·006
5		,,	,,	,,	0·52	0·061	0·005
6		,,	,,	,,	0·51	0·060	0·005
7		,,	,,	,,	0·51	0·059	0·005
8		,,	,,	,,	0·51	0·060	0·005
9		,,	,,	,,	0·51	0·060	0·007
10		,,	,,	,,	0·49	0·060	0·007
11		,,	,,	,,	0·48	0·060	0·007
12		,,	,,	,,	0·48	0·059	0·005
13		,,	,,	,,	0·52	0·076	0·005
14		,,	,,	,,	0·55	0·103	0·010
15		,,	,,	,,	0·57	0·109	0·019
16		,,	,,	,,	0·52	0·098	0·027
17	Top	,,	,,	,,	0·55	0·099	0·029

for a longer period the segregation would have been more marked.

Since it is necessary to allow a certain time to elapse for the flotation of the sulphur to the surface to be completed, it is more practicable to start initially with a relatively low sulphur content, preferably below 0·06%, when desulphurization to the required low figure can be achieved in a few seconds. With metal of high initial sulphur content the apparent yield of cerium (as determined by chemical analysis of the casting) depends upon the extent of desulphurization. If desulphurization occurs the yield of cerium will be low, but if desulphurization is not effected the apparent yield of cerium will be high but much of the element will be combined with the sulphur and hence will not function to produce the nodular structures. As an instance of the desulphurizing influence of cerium, the figures given in Table VI may be quoted for the treatment of a cupola-melted nickel–copper–chromium austenitic iron (Niresist).

The figures given in Table VI clearly indicate that the cerium content alone is not the sole determining factor for nodular structures, but it has to be considered along with the sulphur content.

When hyper-eutectic cast irons containing too high a proportion of sulphur are treated with *mischmetall* in insufficient amount, appreciably to lower the sulphur content, the hyper-eutectic graphite is frequently obtained in star-shaped aggregates.

Table VI

DESULPHURIZING EFFECT OF CERIUM

Addition of Ce as *Mischmetall*, %	S, %	Ce by Analysis, %	Structure
0·1	0·099	0·066	Flake graphite
0·2	0·051	0·071	Flake graphite
0·3	0·014	0·063	Nodular graphite

A typical example of this is shown in Fig. 30, taken from an iron cast in the form of a 1·2-in. dia. bar, having the composition :

Total C, %	Si, %	Mn, %	S, %	P, %	Ce, %
3·75	2·60	0·98	0·098	0·033	0·051

These star-shaped aggregates are frequently found to be associated with extensive manganese sulphide segregations, such as are illustrated in Fig. 31. The actual sulphide particles in these segregations frequently have duplex structures and a typical example is shown in Fig. 32, in which a duplex sulphide particle lies at the centre of a mass of hyper-eutectic graphite. Both phases in these sulphide aggregates are dove grey in colour; the lighter one is more likely to be manganese sulphide and it is suggested that the darker phase contains cerium.

At this stage it is interesting to recall that in the earlier work[1,2] on nickel–carbon alloys, nodular structures could not be produced in the presence of high sulphur. With regard to cast irons it is not yet apparent whether low sulphur is an absolute essential for the production of nodular structures or whether the sulphur has to be low merely to permit the solution of some cerium.

For the commercial production of nodular cast irons, which it is not proposed to discuss here, it is necessary to use low sulphur contents in order to limit the amount of the expensive cerium alloy used. However, it should be noted that the metal may be desulphurized with soda-ash before making the cerium addition, without influencing the production of nodular structures beyond reducing the amount of cerium required.

THE MECHANISM OF SOLIDIFICATION OF CERIUM-TREATED NODULAR IRONS

The investigation of the mechanism of solidification of cerium-treated nodular irons is made difficult by the fact that upon remelting such irons tend to lose cerium. This appears to be due to oxidation, and under some conditions the loss may be as high as 100% of the initial cerium content. The extent of

Table VII
INFLUENCE OF REMELTING

	Total C, %	Si, %	Mn, %	S, %	P, %	Ce, %
Pig iron before melting	3·99	2·57	0·96	0·011	0·042	—
Remelted pig iron with cerium addition ...	3·70	2·57	0·82	0·010	0·040	0·053
Remelted cerium-treated material	3·63	2·51	0·74	0·007	0·041	0·005

the cerium loss depends upon the manner and speed of remelting. Slow melting under oxidizing conditions causes the greatest losses. In cupola melting there will also be a loss of cerium due to its reaction with the sulphur in the coke. Obviously, any attempt to use cerium for the production of nodular structures must involve the addition of the element to the molten cast iron shortly before casting. When cerium-treated nodular cast irons are remelted and the final cerium content falls below about 0·02%, the graphite reverts to a normal flake structure. As an instance of the loss of cerium on remelting, the following experiment may be quoted. Hematite pig iron, 270 lb. in weight, was melted in an oil-fired crucible furnace. When the charge had reached a temperature of 1430° C., 320 g. of *mischmetall* were added and the metal was cast into small pigs. After cooling, these pigs were then remelted in the same furnace and the metal was again cast when the temperature had reached 1430° C. The total melting time in each case was 5½ hr. The analyses of the materials used and cast are given in Table VII.

The material cast immediately after the cerium addition had a mixed structure of nodules and quasi-flake graphite, but after remelting this material reverted to a normal flake-graphite structure. This suggests that the production of the nodular structures depends not only upon the low sulphur content, but also upon the presence of cerium.

Cooling curves have been taken upon cerium-treated nodular irons by taking special precautions to ensure that sufficient cerium remained in the cooling-curve ingots during solidification. This was accomplished by remelting, in a small fireclay crucible, an iron of the following composition :

Total C, %	Si, %	Mn, %	S, %	P, %	Ce, %
3·91	2·71	0·51	0·006	0·024	0·049

When molten, a further addition of *mischmetall* was made to give a cerium content of the order of 0·1%, and small amounts were sucked into silica tubes to provide suitable samples for 10 g. cooling-curve ingots. These 10-g. samples were melted in small silica crucibles which have been described previously (*see* Fig. 132 of ref. 1), and after taking cooling curves gave cerium contents of 0·04–0·06%. The cooling curves obtained were all very similar : two arrests were obtained in each case, one beginning at a temperature of between 1150° and 1160° C. and the second and longer arrest about 5°–10° C. lower. A typical cooling curve is shown in Fig. 33. On slow cooling to room temperature, such samples had well-developed hyper-eutectic spherulites with quasi-flake graphite. After quenching from a temperature of 1087° C. a sample was found to be completely graphitized and to have the same graphite structure as the slowly cooled specimen, but when quenching was carried out just after complete solidification, that is, after the termination of the second arrest, the samples were substantially white with some small and some large graphite spherulites. An area of white iron containing small graphite spherulites is shown in Fig. 34, in which the carbide is acicular. The large nodules were usually duplex in structure and were surrounded in every case by a zone free from carbide, as in Fig. 35. This suggests that the hyper-eutectic spherulites form very early in solidification and, in their vicinity, graphitization proceeds very rapidly by deposition on the hyper-eutectic nuclei. Ingots quenched from temperatures between the two arrest points and also from above the first arrest point had structures very similar to that illustrated in Fig. 34 ; fine spherulites in a background of acicular white-iron eutectic.

The evidence obtained from these cooling-curve experiments is not entirely complete or definite. The first arrest could correspond with the formation of the hyper-eutectic phase (but, as will be shown later, other possibilities exist), and the second arrest

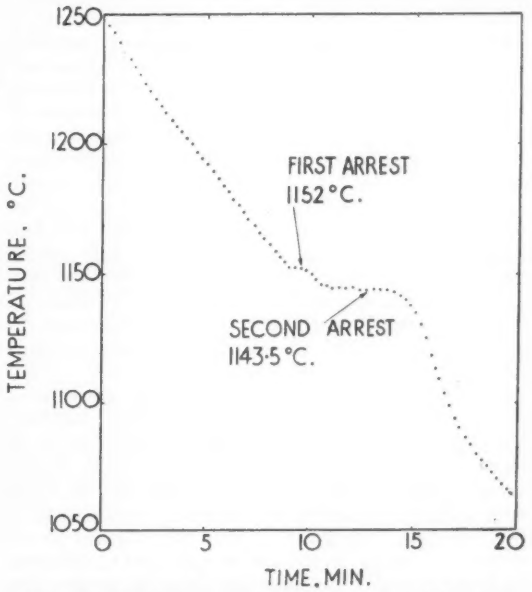

Fig. 33—Cooling curve on cerium-treated hypo-eutectic iron

Table VIII

COMPOSITION AND MECHANICAL PROPERTIES AT TOP SURFACE OF HEAVY-SECTION CASTING

Bar Size	Total C, %	Si, %	Mn, %	S, %	P, %	Ce, %	Transverse Rupture Stress, tons/sq. in.	Deflection, in.	Brinell Hardness No.	Tensile Strength, tons/sq. in
1·2 in. dia.	3·18	4·69	1·38	0·018	0·028	0·045	35·6	0·21	252	23·2

to the solidification of a white-iron eutectic. The white-iron eutectic may decompose shortly after solidification. In the vicinity of the hyper-eutectic spherulites the graphite arising from this decomposition is deposited upon the already existing spherulite, but at distant points it forms as quasi-flake graphite. Each hyper-eutectic spherulite appears to have a sphere of influence beyond which the quasi-flake graphite forms. Thus, if the number of hyper-eutectic spherulites can be increased so that their spheres of influence overlap, it should be possible to obtain the whole of the graphite structure in the spherulitic form. That this is so will be demonstrated later.

It is possible that the first arrest does not correspond to the formation of hyper-eutectic spherulites and that these are formed at higher temperatures. The present investigators have never obtained an arrest in any cooling curves of untreated hyper-eutectic irons for the deposition of the hyper-eutectic graphite. It is perhaps significant that the hyper-eutectic liquidus for the stable iron–carbon equilibrium diagram has been obtained not by cooling curve data, but by quenching the alloys, melted in graphite crucibles, from various temperatures and then by plotting the carbon content against the temperature from which they were quenched. Perhaps the thermal change corresponding to the deposition of graphite from the melt is too small to be detected by normal cooling-curve technique. There is evidence, however, that normal hyper-eutectic flake graphite is deposited from the melt, in irons of carbon and silicon contents similar to those used here, at higher temperatures than that of the first arrest shown in the cooling curve of Fig. 33. For instance, 270 lb. of a hematite pig iron were melted in a crucible furnace, and five ladles, each containing 50 lb. of metal were taken, the first ladle being treated with 50 g. of *mischmetall* when the metal temperature was 1430° C., the second at 1390° C., the third at 1360° C., the fourth at 1327° C. and the fifth at 1298° C. All the metal temperatures were taken with an immersion pyrometer. Test-bars poured from the first four ladles all had spherulitic hyper-eutectic nodules and quasi-flake graphite, but test-bars from the fifth ladle had, in addition to these forms of graphite, some normal flake hyper-eutectic graphite, as illustrated in Fig. 36. It would seem that the graphite had already begun to form between 1327° and 1298° C. and once formed in the metal, the cerium would not be expected to influence its appearance. These graphite flakes have therefore been precipitated from the melt much above the first arrest of the cooling curves. The composition of the material cast from the fifth ladle was found by analysis to be :

Total C, %	Si, %	Mn, %	S, %	P, %	Ce, %
3·88	2·70	0·49	0·019	0·036	0·046

If the first arrest does represent the formation of hyper-eutectic spherulites, the cerium addition must cause considerable undercooling compared with untreated alloys. On the other hand, if the arrest is not due to the formation of graphite spherulites the " eutectic " solidification must be more complex than appears. Although these alloys are hyper-eutectic they always show evidence of primary austenite dendrites. This is to be expected if undercooling in these treated alloys follows the same type of process as in the betol–salol system,[1] in which case deposition of hyper-eutectic spherulites should take place with undercooling beyond the normal eutectic and then a deposition of austenite dendrites should occur until the white-iron eutectic solidifies. The deposition of austenite dendrites would then correspond to the first arrest. There is some evidence that this may be so, since in one cerium-containing iron, quenched between the two arrest points, dendrites of two sizes were found, the coarser being, perhaps, deposited before the quench, and the finer during the quench.

The cooling-curve experiments indicate that the hyper-eutectic spherulites form very readily and that their formation is not inhibited by rapid cooling. Previously it has been supposed that nodular graphite can only form in cast irons as the result of the decomposition of solid iron carbide. If the hyper-eutectic spherulites form by such a process, the decomposition of the carbide must be extremely rapid. The same problem has been discussed in connection with the flotation of hyper-eutectic spherulites in nickel–carbon alloys (*see* page 356 of ref. 1). It seems certain that they exist in the liquid melt, whether they form *via* a carbide or whether they form directly from the melt, or they would not tend to float to the top of a melt. The centrifugal casting of cerium-treated hyper-eutectic cast irons throws some interesting light upon this subject. It has been found during the centrifugal casting of sand-spun liners that the hyper-eutectic nodules are forced to the inner surface of the casting. Figure 37 provides an illustration of this effect. This micrograph was taken from a liner of the following composition :

Total C, %	Si, %	Mn, %	S, %	P, %	Ce, %
3·80	2·50	0·82	0·019	0·032	0·087

The segregation of hyper-eutectic nodules at the inner surface (top of the micrograph) can be clearly seen. It is difficult to imagine how this could have

Fig. 34—Area of white iron with small spherulites, in cooling-curve ingot quenched just after solidification. Etched in picric acid × 600

Fig. 35—Large graphite spherulites in cooling curve ingot quenched just after solidification. Etched in picric acid × 600

Fig. 36—Area of normal flake graphite in sample treated at 1298° C. Unetched × 100

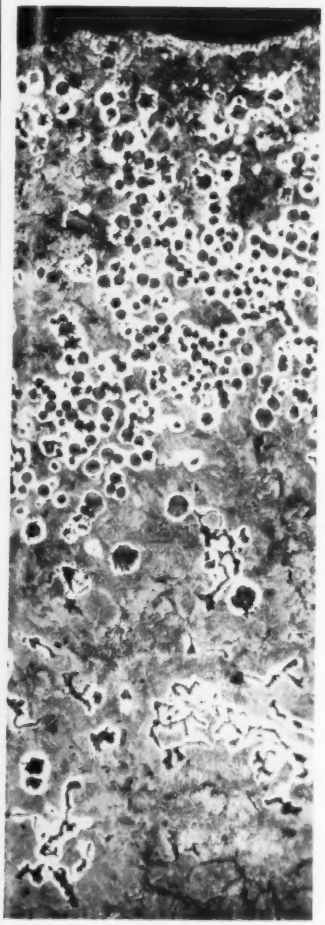

Fig. 37—Segregation of hyper-eutectic nodules at inner surface of sand-spun liner made in cerium-treated hyper-eutectic cast iron. Etched in picric acid × 60

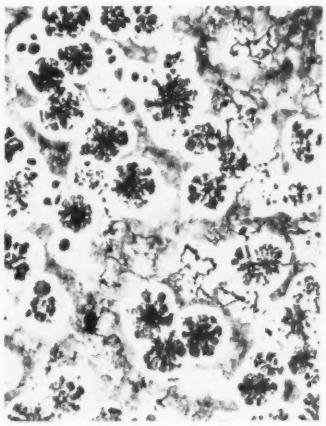

Fig. 38—Segregation of imperfect hyper-eutectic nodules in nodular cast iron. Etched in picric acid × 60

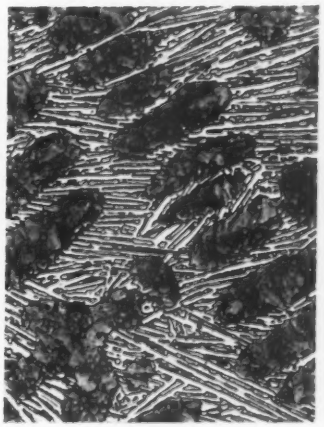

Fig. 39—Inverse chill in a nodular cast iron. Etched in picric acid × 60

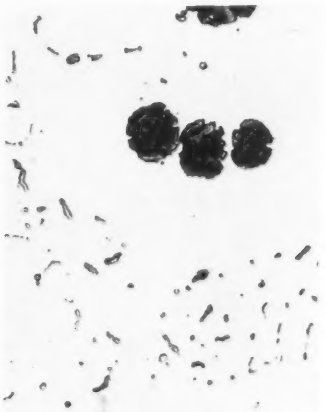

Fig. 40—Cerium-treated high silicon cast iron. Etched in solution of HF and HNO_3 in glycerol × 600

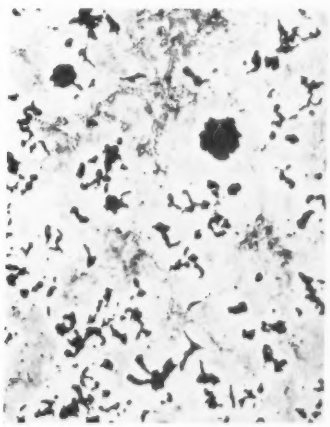

Fig. 41—General structure of 1·2-in. bar with cerium addition (No. 1, Table XII). Etched in picric acid × 60

[*Morrogh and Williams*

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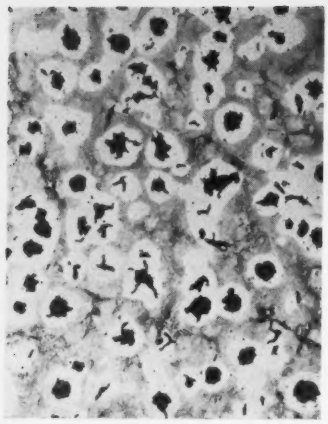

Fig. 42—General structure of 1·2-in. bar, cerium and S.M.Z. addition (No. 4, Table XII). Etched in picric acid × 60

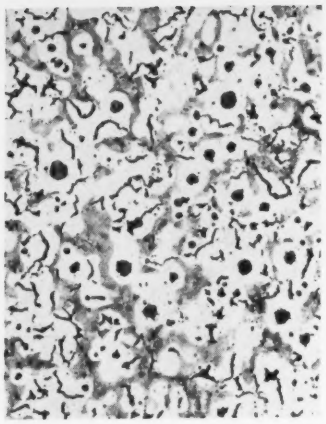

Fig. 43—General structure of 1·2-in. bar (No. 1, Tables XIII and XIV). Etched in picric acid × 60

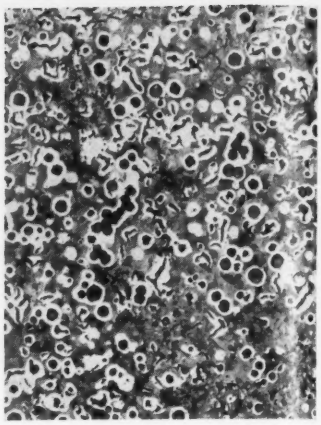

Fig. 44—General structure of 0·6-in. bar (No. 1, Tables XIII and XIV). Etched in picric acid × 60

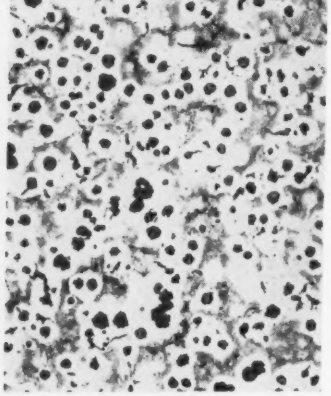

Fig. 45—General structure of 1·2-in. bar (No. 4, Tables XIII and XIV). Etched in picric acid × 60

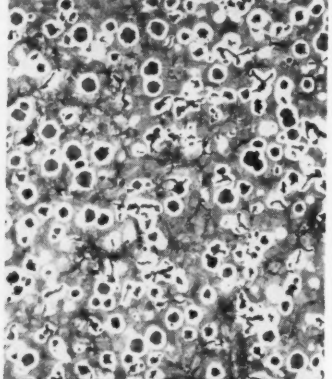

Fig. 46—General structure of 0·6-in. bar (No. 4, Tables XIII and XIV). Etched in picric acid × 60

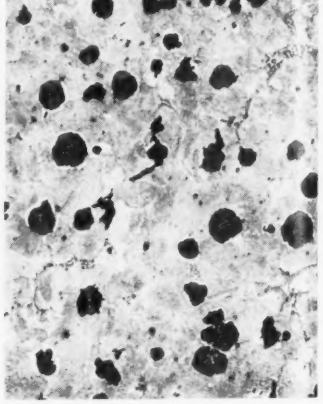

Fig. 47—General structure of 0·6-in. bar alloyed with copper. Etched in picric acid × 150

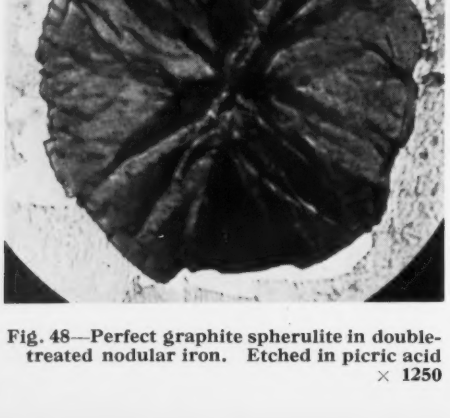

Fig. 48—Perfect graphite spherulite in double-treated nodular iron. Etched in picric acid × 1250

Fig. 49—Imperfect spherulite in double-treated nodular cast iron. Etched in picric acid × 1000

[*Morrogh and William*

[*To face p. 31*

Table IX

INFLUENCE OF SILICON ON MECHANICAL PROPERTIES OF CERIUM-TREATED NODULAR IRONS

No.	Total C, %	Si, %	Mn, %	S, %	P, %	Ce, %	Transverse Rupture Stress, tons/sq. in.	Deflection, in.	Tensile Strength, tons/sq. in.	Brinell Hardness No.	Impact, ft. lb.
1	3·68	2·70	0·53	0·010	0·030	0·045	45·1	0·45	23·8	189	43
2	3·67	3·20	0·51	0·013	0·032	0·048	43·0	0·34	23·3	190	28
3	3·59	3·45	0·49	0·012	0·034	0·043	47·1	0·41	24·6	193	29
4	3·35	4·00	0·51	0·004	0·032	0·045	50·8	0·32	28·1	210	24
5	3·35	4·66	0·52	0·009	0·030	0·043	52·5	0·34	29·0	229	16

occurred except by the existence of the spherulites before the "eutectic" had solidified. Figure 37 also has another interesting feature. It will be noticed that in the region of the segregation no quasi-flake graphite exists, but where the structure is entirely devoid of hyper-eutectic spherulites all the graphite is in the quasi-flake form. This has a bearing upon what has been said earlier. In the region of the segregation, the hyper-eutectic spherulites are so close together that their "spheres of influence" on the "eutectic" graphite overlap, all the "eutectic" graphite has crystallized on these nuclei and no quasi-flake graphite has thus formed. The distance over which a hyper-eutectic spherulite influences the crystallization of the graphite arising from the decomposition of the "eutectic" carbide is probably a function of the ability of the carbon to diffuse through the austenite surrounding the hyper-eutectic nucleus under the conditions operating at the time.

When making castings in relatively heavy sections using hyper-eutectic nodular cast irons there is a tendency for the segregation of the hyper-eutectic nodules to the top surface of the castings, particularly when the carbon is very much in excess of the eutectic concentration. A typical example of this is shown in Fig. 38 for an iron having the composition and mechanical properties given in Table VIII.

In such segregations the spherulites are usually imperfectly formed as can be seen in Fig. 38. These imperfect nodules are similar to those illustrated previously for cerium-treated pure iron–nickel–carbon melts. The present authors have no explanation for these structures, but it does appear that when the carbon content is considerably in excess of the "eutectic" concentration and when flotation can occur, partial spherulites grow by a process other that that of uniform concentric crystallization.

Inverse chill occurring in undercooled graphite irons has been discussed previously[1,2] and the suggestion was put forward that this defect occurs because the irons solidify white and graphitize after solidification, the conditions operating in the central zones of a section sometimes being particularly unfavourable to graphitization. Since nodular irons solidify by a similar process it is not surprising that they also are prone to inverse chill in the centre of relatively thin sections. Figure 39 shows an area of inverse chill in the centre of a 0·6-in. dia. bar having the following composition :

Total C, %	Si, %	Mn, %	S, %	P, %	Cu, %	Ce, %
3·80	2·20	0·91	0·008	0·056	2·20	0·054

The structure has the acicular form of carbide very similar to that described previously.[1,2] The reason for the occurrence of this form of inverse chill is not easy to explain, but it may be suggested that in irons which solidify white and graphitize after solidification, any mechanical restriction of the expansion due to graphitization should inhibit graphite formation. Such a condition might conceivably arise at the centre of a section.

Further evidence that nodular cast irons solidify white and graphitize after solidification is suggested by a study of the dimensions and shapes of small castings when feeding is very efficiently carried out. In such circumstances, due to the thin sections, solidification at the centre occurs a short time after the edge of the section. Thus the whole of the section solidifies white and graphitizes more or less simultaneously. When feeding is very effective and no porosity cavities occur, the sides of such castings bulge outwards slightly under the pressure of graphitization. This does not occur in heavy sections, presumably because the parts which solidify first begin to graphitize before the whole of the section has solidified and expansion takes place by displacement of the liquid.

INFLUENCE OF SILICON IN NODULAR CAST IRONS

It has been found that nodular cast irons can be produced with a wide range of silicon contents provided the alloy is hyper-eutectic. Owing to the tendency to chill white, it is not advisable to use a silicon content of less than 2·3% or its equivalent (where silicon equivalent = actual silicon content + $\frac{1}{3}$ Ni(%) + $\frac{1}{3}$ Cu(%) except in heavy or slowly cooled sections.

Within the range 2·3–5% of silicon, variations in silicon content have no influence on the production of nodular structures. Increasing silicon within this range has the effect of slightly raising the tensile strength, increasing the hardness, and lowering the shock-resistance. The following figures (Table IX) obtained on crucible-melted material indicate the influence of silicon on treated samples cast in the form of 1·2-in. bars. The graphite structures of these bars were all very similar, having well-developed hyper-eutectic nodules and quasi-flake graphite. The matrix of bar No. 1 consisted of about 60% of ferrite and 40% of pearlite. With increasing silicon, the amount of pearlite decreased until bar No. 5, with 4·66% of silicon, contained only about 2% of this constituent. The melts from which these bars

were cast were made up from a high carbon pig containing 2·8% of silicon and an appropriate amount of ferrosilicon (80% of Si) in the case of bars Nos. 2–5. Increasing silicon has the effect of lowering the final carbon content, due largely to the influence of this element in lowering the solubility of carbon in the melt. In spite of the decreasing amount of pearlite in these bars with increasing silicon content, the hardness increases due to the hardening effect of silicon dissolved in ferrite. This dissolved silicon is also responsible for the increase in tensile strength and decreasing shock-resistance.

With silicon contents in excess of about 6%, the yield of cerium from a given addition of *mischmetall* appears to improve, but the irons take on a greater tendency to chill. When the silicon is in excess of about 10% it has been found that only the hypereutectic graphite can be obtained in the spherulitic form, the remainder existing in a very finely divided form resembling undercooled graphite. A typical example of this structure is shown in Fig. 40 for an iron of the following composition :

Total C, %	Si, %	Mn, %	S, %	P, %	Ce, %
0·93	14·50	0·59	0·015	0·038	0·118

INFLUENCE OF PHOSPHORUS IN NODULAR CAST IRONS

As has been mentioned earlier in this paper, the use of cerium for the production of nodular structures cannot be extended to irons with phosphorus contents in excess of 0·5%. Phosphorus appears to have the effect of reducing the solubility of cerium in cast iron, and with phosphorus in excess of 0·5% it is not possible to hold sufficient cerium in the melt to have the desired effect.

INFLUENCE OF GASES

In the experiments on nickel–carbon alloys treated with calcium silicide it was found that hydrogen or carbon dioxide bubbled through the melt after the addition prevented the formation of spherulites.[1] In view of the known effects of gases upon cast iron[19] some interest attaches to their possible influence upon cerium-treated nodular irons. It can be stated that hydrogen, carbon dioxide, and nitrogen do not appear to influence the ability of cerium to give nodular structures. It has been found, however, that when these gases are bubbled through molten cerium-containing cast irons to give a vigorous churning action, a loss of cerium occurs, probably due to oxidation. The structures obtained upon subsequent casting depend entirely upon the amount of cerium remaining in the melt.

To illustrate the effect of this gas treatment three crucible melts were carried out, the charge in each case being 260 lb. of hematite pig iron. When the metal temperatures had reached 1450° C., 250 g. of *mischmetall* were added in each case and stirred in with a refractory plunger. Fifty pounds of metal were then taken from each melt and a number of

Table X

INFLUENCE OF GAS BUBBLING

Melt	Gas	Tap	Total C, %	Si, %	Mn, %	S, %	Ce, %	Tensile Strength, tons/sq. in.	Microstructure
	None	1	3·76	2·70	0·50	0·011	0·063	26·5	Spherulites + compact quasi-flake
		2					0·025	21·0	Spherulites + lamellar quasi-flake
1	H_2	3					0·025	20·3	,, ,, ,,
		4					0·015	8·7	Coarse, normal flake + undercooled
	None	1	3·84	2·69	0·53	0·009	0·071	24·9	Spherulites + compact quasi-flake
		2					0·029	17·2	Spherulites + lamellar quasi-flake
2	CO_2	3					0·025	17·3	Some undercooled ± quasi-flake
		4					0·020	17·2	Some undercooled + quasi-flake
	None	1	3·72	2·66	0·49	0·012	0·070	23·7	Spherulites + compact quasi-flake
		2					0·030	18·8	Spherulites + lamellar quasi-flake
3	N_2	3					0·018	8·5	Normal flake + undercooled
		4					0·018	12·3	,, ,, ,,

test-bars were poured. A gas was then bubbled vigorously through each melt for 2 min.; three more 50-lb. taps were taken at 2-min. intervals, and similar test-bars were poured from each, the gas being passed through the melt continuously. The gas used for the first melt was commercial hydrogen, that for the second melt was commercial carbon dioxide, and that for the third melt was commercial nitrogen. The chemical analyses, tensile strengths and microstructures of 1·6-in. dia. bars cast from these melts are given in Table X.

These results show the gradual drop in cerium content during the bubbling process and they do not indicate any special effect for any particular gas. As the cerium contents drop from the high initial value the quasi-flake graphite becomes more lamellar in appearance until at approximately 0·02% of cerium some normal graphite appears, and with cerium contents below this value a reversion to a normal structure occurs. The tensile strength shows a marked drop when the normal graphite structure is obtained. Similar results, in the reverse direction are obtained when increasing amounts of cerium are added to a similar iron.

DOUBLE-TREATMENT PROCESS (CERIUM ADDITION PLUS INOCULATING ADDITION)

In an earlier section of this paper dealing with the mechanism of solidification of nodular cast irons it was pointed out that if the number of hyper-eutectic nuclei could be increased it should be possible to obtain the whole of the graphite structure in the nodular form. Attempts were made to do this by treating the metal with a graphitizing inoculant before making the *mischmetall* addition, and some slight improvement in mechanical properties and structures was obtained. When, however, the graphitizing inoculant was added after the *mischmetall*, completely nodular structures with a pronounced improvement in mechanical properties resulted. Similar results were also obtained when the two additions were made simultaneously, but in such circumstances the *mischmetall* always dissolves more rapidly than the graphitizing inoculants which have been used. Among the inoculants which have been tried the 80% grade of ferrosilicon, S.M.Z.,* and calcium silicide have been satisfactory, but the first two appear to give the best results. This treatment, involving the addition of *mischmetall* and a graphitizing inoculant, will be referred to as the "double-treatment process."

As an illustration of the effect of adding an inoculant after the cerium, the following example may be given. Three ladles each containing 50 lb. of remelted pig iron were treated with the following additions, in the order given :

Ladle 1 60 g. of *mischmetall*
Ladle 2 6 oz. of S.M.Z. and then 60 g. of *mischmetall*
Ladle 3 60 g. of *mischmetall* and then 6 oz. of S.M.Z.

Four 1·2-in. bars were cast from each ladle, and in Table XI the average mechanical properties of these bars are given, together with the chemical analyses.

The mechanical properties of the material cast from ladle No. 3 are seen to be consistently higher than those of the materials cast from ladles Nos. 1 and 2. The impact value is appreciably higher in the third case. The microstructures of the first two irons had hyper-eutectic nodules, together with quasi-flake graphite, but the third iron had an entirely nodular graphite structure. The matrix structure was the same in each case, consisting of about 40% of pearlite and 60% of ferrite.

So far, experience has shown that S.M.Z. or 80% ferrosilicon should be used in sufficient amount to give an increase in silicon of between 0·3 and 0·5%. No particular advantage appears to be obtained by adding more of the inoculant than this.

The results given in Table XII illustrate the effect of varying the amount of S.M.Z. and ferrosilicon for the same addition of *mischmetall* in each case. These figures are average values obtained from four 1·2-in. bars in each case from 50 lb. of metal treated as follows :

No. 1 70 g. of *mischmetall*
No. 2 70 g. of *mischmetall* and then 2 oz. of S.M.Z.
No. 3 70 g. of *mischmetall* and then 4 oz. of S.M.Z.
No. 4 70 g. of *mischmetall* and then 8 oz. of S.M.Z.
No. 5 70 g. of *mischmetall* and then 2 oz. of 80% ferrosilicon
No. 6 70 g. of *mischmetall* and then 4 oz. of 80% ferrosilicon
No. 7 70 g. of *mischmetall* and then 8 oz. of 80% ferrosilicon

The influence of increasing amounts of inoculant upon irons of the same cerium content is to replace the mixed structure of spherulites and quasi-flake graphite with a uniform structure in which all the

* S.M.Z. is a proprietary silicon–manganese–zirconium alloy containing approximately 63% of silicon, 6% of manganese, 6% of zirconium, and 20% of iron.

Table XI

EFFECT OF ADDING INOCULANT BEFORE AND AFTER CERIUM ADDITION

Ladle	Total C, %	Si, %	Mn, %	S, %	P, %	Ce, %	Transverse Rupture Stress, tons/sq. in.	Deflection, in.	Tensile Strength, tons/sq. in.	Brinell Hardness No.	Impact, ft. lb.
1	3·77	2·65	0·49	0·009	0·030	0·055	44·0	0·43	23·6	190	35
2	3·80	2·95	0·57	0·009	0·030	0·043	48·1	0·49	24·7	192	33
3	3·62	2·76	0·53	0·007	0·032	0·038	58·9	0·80	30·7	209	82

Table XII

INFLUENCE OF VARIOUS AMOUNTS OF INOCULANT ADDED AFTER CERIUM

No.		Total C, %	Si, %	Mn, %	S, %	P, %	Ce, %	Transverse Rupture Stress, tons/sq. in.	Deflection, in.	Tensile Strength tons/sq. in.	Brinell Hardness No.	Impact, ft. lb.	Shear Strength tons/sq. in.	Compression Strength tons/sq. in.
1		3·67	2·67	0·86	0·005	0·051	0·040	56·9	0·60	26·0	221	54	26·4	53·4
2	S.M.Z.	3·66	2·84				0·055	62·5	0·63	33·1	244	60	28·9	67·3
3		3·57	2·93				0·055	62·7	0·59	32·4	240	78	28·7	60·9
4		3·53	3·05				0·055	63·9	0·63	32·3	239	78	27·9	63·7
5	Ferro-silicon	3·52	2·73	0·88	0·008	0·055	0·051	61·6	0·60	31·7	233	91	28·9	64·6
6		3·49	2·89				0·058	62·0	0·60	33·4	238	84	28·7	64·5
7		3·50	3·03				0·061	63·4	0·77	33·8	231	70	27·4	64·2

Table XIII

CHEMICAL ANALYSIS AFTER DOUBLE TREATMENT

No.	Total C, %	Si, %	Mn, %	S, %	P, %	Ce, %
1	3·90	2·96	0·51	0·006	0·024	0·016
2	3·76	3·09	—	0·008	—	0·021
3	3·90	3·10	—	0·007	—	0·031
4	3·91	3·08	—	0·003	—	0·036
5	3·75	3·11	—	0·004	—	0·063

graphite is in the spherulitic form, the perfection of the structure increasing with increasing amount of inoculant up to an addition corresponding to an increase in silicon of about 0·5%. Beyond this no further improvement appears to result. Although this progressive change in structure occurred in the bars listed in Table XII, no further improvement in mechanical properties was obtained after the first addition of inoculant. The structure of the plain cerium-treated bar No. 1 (Table XII) is shown in Fig. 41, and that of bar No. 4, with the largest addition of S.M.Z., in Fig. 42.

Table XIV

MECHANICAL PROPERTIES OF DOUBLE-TREATMENT NODULAR IRONS WITH VARIOUS CERIUM CONTENTS

No.	Bar Size, in.	Transverse Rupture Stress, tons/sq. in.	Deflection, in.	Tensile Strength, tons/sq. in.	Brinell Hardness No.	Impact, ft. lb.	Shear Strength, tons/sq. in.	Compression Strength, tons/sq. in.	Modulus of Elasticity,* $\times 10^{-6}$ lb./sq. in.
1	1·6	46·6	0·51	24·5	179	32	25·9	53·7	21·7
	1·2	51·0	0·68	27·0	189	46			
	0·875	54·8	0·39	28·1	213	76			
	0·6	63·3	0·35	33·9	239			69·2	
2	1·6	50·0	0·55	26·3	187	37	25·5	57·6	22·6
	1·2	58·4	0·85	31·2	191	64			
	0·875	64·5	0·52	32·2	224	111			
	0·6	62·4	0·28	36·1	255			70·1	
3	1·6	59·3	0·90	32·8	190	89	26·7	61·6	23·8
	1·2	63·8	1·02	33·0	199	120			
	0·875	68·0	0·66	34·5	231	120			
	0·6	73·2	0·43	43·8	252			70·8	
4	1·6	52·9	0·55	32·9	194	120	28·9	61·6	24·3
	1·2	62·2	1·05	33·0	209	120			
	0·875	69·6	0·64	34·5	236	120			
	0·6	76·0	0·45	35·3	257			70·0	
5	1·6	59·0	0·55	30·9	204	53	28·9	62·1	24·3
	1·2	63·6	0·90	29·2	225	60			
	0·875	72·1	0·50	35·7	236	58			
	0·6	74·4	0·35	39·0	257			68·8	

* Determined from transverse test.

Table XV

MECHANICAL PROPERTIES OF AN ALLOYED DOUBLE-TREATED NODULAR CAST IRON

Bar Size, in.	Transverse Rupture Stress, tons/sq. in.	Deflection, in.	Tensile Strength, tons/sq. in.	Brinell Hardness No.	Impact, ft. lb.	Compression Strength, tons/sq. in.
1·6	67·3	0·30	39·8	260	88	78·9
1·2	70·0	0·40	35·4	288	92	
0·875	80·8	0·30	43·1	302	94	
0·6	92·3	0·27	46·4	333		93·8

For the double-treatment process there is an optimum amount of cerium which must be added in order to achieve the best mechanical properties. This is illustrated by the results given in Table XIV. This Table gives the mechanical properties of five sets of test-bars of various sizes cast from metal treated in each case with the same amount of inoculant, *i.e.*, 5 oz. of S.M.Z. to 50 lb. of metal, but with varying amounts of *mischmetall* as indicated below :

No. 1 40 g. of *mischmetall*
No. 2 50 g. of *mischmetall*
No. 3 60 g. of *mischmetall*
No. 4 70 g. of *mischmetall*
No. 5 80 g. of *mischmetall*

The chemical analyses of this series are given in Table XIII.

From set No. 1 to set No. 4 the microstructures of these bars showed a progressive improvement, particularly in the larger sections. The microstructures of the 1·2-in. and 0·6-in. bars from set No. 1 are shown in Figs. 43 and 44, and those of the 1·2-in. and 0·6-in. bars from set No. 4 in Figs. 45 and 46. The bars from set No. 5, with the highest cerium addition had fewer, and hence coarser, nodules than the bars from the other sets. The lower impact values of set No. 5 may be related to the coarser nodule size.

By the use of special alloying elements in nodular irons an extremely high level of mechanical properties may be achieved if the double-treatment technique is applied. The example given in Table XV will serve to illustrate this. The analysis of the bars in this instance was as follows :

Total C, %	Si, %	Mn, %	S, %	P, %	Cu, %	Ce, %
3·80	2·17	0·92	0·015	0·052	2·17	0·054

The structure of this material showed a uniform distribution of well-formed nodules ; in the 1·6-in. bar there was about 10% of ferrite and in the 0·6-in. bar there were only traces of ferrite, the matrix being almost entirely pearlitic. This latter structure is illustrated in Fig. 47.

The reasons for the effect of the inoculant in the double-treatment process are not entirely clear, but it is suggested that the number of hyper-eutectic spherulites is increased so that their "fields of influence" upon the "eutectic" graphite overlap and thus entirely spherulitic structures result. If this explanation is correct it remains to determine by what process the inoculant increases the number of hyper-eutectic spherulites and why the double treatment is more effective when the inoculant is added after the cerium instead of before it. Eash has suggested that the normal inoculating effect of ferrosilicon is due to localized silicon concentrations reducing the solubility of carbon in the melt ; such silicon concentrations causing the iron to become locally hyper-eutectic and giving a fine deposition of hyper-eutectic graphite particles which nucleate the melt. If such a process occurs it would follow that these fine particles might nucleate the precipitation of hyper-eutectic spherulites in cerium-treated irons, but it is difficult to imagine why this only occurs after the cerium addition has been made. In any case it should be remembered that many objections can be raised to Eash's theory.[20]

Cerium-containing nodular cast irons are much less prone to chilling when the double-treatment process is applied, and much higher cerium contents can be tolerated without fear of white iron forming. This is consistent with the idea that the inoculant increases the number of hyper-eutectic spherulites.

The individual nodules in double-treated irons frequently have a perfect spherulitic structure, such as is shown in Fig. 48, with no evidence of a marked peripheral layer. Occasionally, imperfect spherulites are obtained, such as is illustrated in Fig. 49, and in these cases there is evidence of a perfect central nucleus with imperfectly formed adherent graphite. Figures 48 and 49 are taken from the 0·6-in. bar (Table XV).

SUMMARY AND CONCLUSIONS

It has now been demonstrated that the production of nodular structures in grey cast irons without heat-treatment is a possibility and that cast irons of an extremely high level of mechanical properties result. The findings of this investigation closely follow upon the previous work upon nickel–carbon alloys and it is felt that the results obtained have justified this rather devious method of investigation. Only a very limited selection of the experimental results has been referred to. A new field in the metallurgy of cast irons has been opened, but it is too early to assess the commercial possibilities of the process, although successful trials on an industrial scale have been carried out. Cast irons having nodular structures in the as-cast state have mechanical properties differing from those of malleable cast iron, which formerly was the only known material having controlled nodular graphite structures. Further papers will be presented in due course dealing with the practical issues involved in the application of this process.

The nodular structures are all of the spherulitic variety and several fresh problems of a theoretical nature arise as a result of the discovery that they can be produced in the manner which has been described. In the malleable-iron process spherulitic nodules are only produced when iron sulphide exists in the iron at the annealing temperature and there may be some relation between the crystal structure of the sulphide particles which act as nuclei and the type of graphite nodule which forms. In the process for the production of as-cast nodular irons one of the essentials is to reduce the sulphur to the lowest possible value.

It is perhaps not surprising that the eutectic graphite should crystallize in a spherulitic form upon an already existing hyper-eutectic spherulite, but the problem is to know what determines that the hyper-eutectic graphite will be spherulitic. Does cerium introduce nuclei into the melt which promote spherulitic crystallization of the hyper-eutectic phase? At the moment there is insufficient information to answer such a question. Perhaps cerium influences the gas content of the metal; this is a subject for future investigation. It is still not clear whether the hyper-eutectic spherulites form directly from the melt or *via* a carbide phase. We shall only obtain the solutions to these problems when we know more about the fundamentals of spherulitic crystallization and in particular their relation to undercooling phenomena.

Acknowledgments

The authors desire to thank the Council of the British Cast Iron Research Association for permission to publish the work recorded in this paper, and also the Director, Mr. J. G. Pearce, for his constant interest and encouragement. They are also indebted to several of their colleagues on the staff of the Association, particularly to Mr. J. W. Grant, who has been associated with the practical application of the work, to Mr. W. Westwood and Mr. A. Mayer for investigating and providing suitable methods for the determination of cerium in cast iron, without which the work would have been seriously handicapped, and finally to Mr. D. Marles of the Association's metallography laboratory.

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Historical Note No. 6

A Eulogy of Iron by Thomas Dekker, in 1629

By Dr. H. R. Schubert

The English dramatist Thomas Dekker lived from 1570 to 1641, contemporary with Shakespeare. In his dramatic works he depicted the life of the middle-class citizens of the London of his day, combining realistic presentation with a vein of sentimental romanticism. In 1629 he prepared a pageant for the Ironmongers' Company of London, for inclusion in the Lord Mayor's show. The pageant was entitled "London's Tempe" and contained a eulogy of iron addressed to Vulcan by Jove. The poet calls the Ironmongers:

> Your worthy brotherhood through whose care goes
> That rare rich prize of iron to the whole land.
> Iron far more worth than Tagus' golden sand!
> Iron best of metals! Pride of minerals!
> Heart of the earth! Hand of the world! Which falls
> Heavy when it strikes home . . .
> Iron that main hinge on which the world doth turn.*

The verses demonstrate that from observation of the middle class he loved the poet had gained a clear view of the economic process going on in his days, in which the use of iron played a constantly increasing part, and that he was fully aware of its great possibilities for the future of the country.

* Quoted from G. Unwin, "The Guilds and Companies of London" (third edition), p. 288. London, 1938.

PROCEEDINGS OF THE INSTITUTE

REPORTS OF COUNCIL - OFFICIAL NOTICES

AUTUMN GENERAL MEETING, 1947

THE AUTUMN MEETING OF THE IRON AND STEEL INSTITUTE was held on Wednesday and Thursday, 12th and 13th November, 1947, under the chairmanship of the President, Dr. C. H. DESCH, F.R.S., at the Offices of the Institute, 4, Grosvenor Gardens, London, S.W.1.

Sessions were held from 10.0 A.M. to 1.0 P.M. and from 2.30 P.M. to 5.0 P.M. on the Wednesday, and from 10.0 A.M. to 12.45 P.M. on the Thursday.

A buffet luncheon was held in the Library of the Institute at 1.0 P.M. on the Wednesday.

The Minutes of the previous meeting, held in London on 15th and 16th May, 1947, were taken as read and confirmed.

NOMINATION OF NEXT PRESIDENT

The **President** (Dr. C. H. Desch, F.R.S.): The Council have nominated as President, to take office in May next, Sir Andrew McCance, D.Sc., F.R.S., Joint Managing Director of Colvilles, Ltd. Sir Andrew McCance joined the Institute in 1914, and became a Member of Council in 1932 and a Vice-President in 1941. He is Chairman of B.I.S.R.A., and has been very closely associated with the work of this Institute.

CHANGES ON THE COUNCIL

The **President**: I have to report that the Council have nominated Mr. W. J. Dawson, Vice-President, an Honorary Vice-President, in recognition of his long and distinguished service to the Institute. They have nominated Mr. James Sinclair Kerr as a Vice-President.

The **Secretary** (Mr. K. Headlam-Morley): I have to report the following changes on the Council:

Mr. T. M. Service to be an Honorary Member of Council in succession to the late Dr. J. W. Donaldson, during his period of office as President of the West of Scotland Iron and Steel Institute.

Mr. W. M. Larke to be an Honorary Member of Council in succession to Mr. C. B. Morrison, during his period of office as President of the Staffordshire Iron and Steel Institute.

Mr. E. A. Davies to be an Honorary Member of Council in succession to Mr. G. J. Jones, during his period of office as President of the Swansea and District Metallurgical Society.

The following are due to retire at the next Annual General Meeting and are eligible for re-election:

Vice-Presidents—Mr. J. R. Menzies-Wilson, Mr. James Mitchell, and Mr. R. Mather.

Members of Council—Mr. I. F. L. Elliot, Mr. C. R. Wheeler, Mr. E. F. Law, Dr. C. Sykes, F.R.S., and Mr. D. A. Oliver.

OTHER ANNOUNCEMENTS

The **Secretary**: The Annual General Meeting, 1948, will be held in London on Wednesday and Thursday, 5th and 6th May. Owing to present conditions it is not proposed to hold the Annual Dinner for Members.

The Autumn General Meeting will be held on Wednesday and Thursday, 10th and 11th November, 1948, in London.

A Blast-Furnace Symposium will be held at the Offices of the Institute on Wednesday and Thursday, 26th and 27th May, 1948, and other meetings to discuss subjects of specialized interest will be announced from time to time.

REMARKS BY THE PRESIDENT

The **President**: We expected that this would be a relatively small meeting, owing to the prevailing conditions, but a small meeting has this advantage, that we can hold it in our own building, and there is no reason why the discussions should not be excellent. I wish to welcome, on behalf of the Council, all the members and visitors present, and especially those from oversea.

We can look back with some satisfaction on the work of the year which is now drawing to a close. In addition to the Annual Meeting in May, a very successful special Summer Meeting was held in Switzerland in July. A large number of members attended. The meetings were exceedingly well arranged, and that is true also of the visits. From Zürich we were able to go to a number of towns, such as Winterthur, Solothurn, Schaffhausen, and so on, to visit works, ending up at Geneva. The arrangements throughout were admirable, and the ladies who accompanied the party found the visit very pleasant.

The Symposium on Powder Metallurgy which we held last June was the first meeting of its kind to be held in this country. There was a good attendance and there were good discussions. It has been necessary to print a second edition of the Special Report in which the papers are published.

Satisfactory meetings were also held in March and June. The first was held jointly with the Institute of British Foundrymen and B.I.S.R.A. to discuss papers of common interest, and the latter jointly with B.I.S.R.A. to discuss some corrosion reports. The Council hope to develop the policy of holding special meetings of this kind for the discussion of specialist papers, without in any way detracting from the general interest of our Annual and Autumn Meetings.

The Iron and Steel Engineers Group, under the able chairmanship of Mr. Cartwright, has been very active. Two good meetings have been held in London, and a third has been arranged for 26th November, 1947, when a series of papers on rolling mills will be discussed. Three full Group Meetings are planned for next year. A particularly welcome development is the holding of joint meetings in the provinces with local societies. Particulars are announced in the *Journal*.

The most important development this year has been the publishing of our monthly *Journal*. I am glad to say that it has been well received, and I think the general opinion is that it is good. Owing to printing difficulties the bound volumes of the *Journal* for 1946 have not yet been issued, but one should be available later this month and the other early next year.

Increased use is being made of our Library and Information Services and these are being developed to be of use to B.I.S.R.A. as well as to our own Members. We are pleased that such cordial collaboration has developed with B.I.S.R.A., and we are much indebted to their Council and to Sir Charles Goodeve, their Director. Development of an Information Service takes time, but abstracts of the technical literature of the world are now available covering the last five or six years, and extensions are being made as quickly as possible. We have adopted the Universal Decimal Classification for this purpose, and a translation of the German edition, made by our staff, is now being considered by the appropriate committee of the British Standards Institution. It takes a little time to acquire a knowledge of this decimal system, but the general experience of librarians is that it works well.

We are indebted to local societies affiliated to the Institute for valuable help. Owing to this, our members have received useful facilities for attending meetings in the provinces, and a full programme has been prepared for this winter. Printing difficulties and the shortage of paper have caused undue delay in publishing some of the papers, but a Special Report is now in the press.

Arrangements have been made for collaborating with a large number of metallurgical institutions overseas. The particulars are published in the *Journal* from time to time. Some important congresses have been held at which we have been represented. One of the most notable was the two-hundredth anniversary of Jernkontoret. A small delegation from this country found this a very interesting occasion. We had two meetings in Stockholm and then made a tour of works in central Sweden. The whole visit was most successful, and the Swedes are to be congratulated on the excellence of the arrangements which they made. Members who were able to attend these meetings in Sweden and Switzerland, two countries not subjected to a regime of austerity, have most pleasant recollections of their visits.

We also had several representatives at the fiftieth anniversary of the Luxemburg Association of Engineers and Industrialists. A very successful meeting was held in the small but delightful capital of that country, and again we visited some of the works in Luxemburg. We were also represented at the centenary of the Association of Engineers of the School of Liège, and last month I, with two others, attended the meetings of the French Metallurgical Society, which was founded as the result of discussions with a French delegation which came over here during the war.

On the educational side, the scheme for National Certificates in Metallurgy has made rapid progress, and I am told that the Ministry of Education is well satisfied. We are grateful to Mr. H. S. Tasker for taking charge of this work as Chairman of the Joint Committee. The Joint Committee on Metallurgical Education has done a good deal of useful work, and is now considering a long-term programme under its new Chairman, Professor Leslie Aitchison, with a view to improving the standard of metallurgical education at all levels. The Mond Nickel Fellowships for 1947, for which we are indebted to Sir William Griffiths and his colleagues, have not yet been awarded, but applications are being considered, and we hope that the first Fellowships will be announced soon. All this work on matters connected with education is shared with other institutes which are concerned with different aspects of metallurgy.

Applications for Carnegie Scholarships are still disappointingly few. This is, I think, evidence that conditions are still far from normal. I should like to take this opportunity of reminding research workers, and especially those employed by iron and steel companies and those working in the universities, that this fund exists and that the Council are prepared to make grants to suitable applicants.

The membership of the Institute is now very much greater than it has ever been before. I shall refer to this later, when today's elections have been announced.

With regard to our relations with the other bodies in this building, as announced at the last meeting, the arrangement by which our Secretary served also as Secretary of the Institute of Metals came to an end on 30th June last, by mutual agreement between the Councils. It is very satisfactory to be able to record the close and happy relationship that is continuing between our two Institutes, our members, and our staffs. I should particularly like to congratulate the Institute of Metals on the success of the Symposium on Internal Stresses in Metals and Alloys which they organized last month.

The Iron and Steel Institute and the Institute of Metals were instrumental in bringing into existence the new Institution of Metallurgists, and we have provided secretarial services as well as accommodation. Our Secretary has been Secretary of the Institution since it was founded a little over two years ago. Now, largely on his suggestion, it has been agreed to bring this arrangement to an end. No exact date has yet been fixed, but we expect that it will be mutually convenient to do this during the first half of next year. That Institution has grown rapidly, and its membership already exceeds 1500. Under these conditions it is appropriate that it should have a separate staff. We hope that the friendly relationship will continue, and that it will be possible for all three societies to continue to have their offices in the same building.

It is another sign of the way in which this Institution has grown that the Ministry of Education has agreed to invite it to join the Joint Committee on National Certificates in Metallurgy.

I have to express our appreciation of the services which have been rendered to the Institute by the Secretary and the members of the staff.

The arrangements for our chief meetings for next year have already been announced, and I do not think that I need on this occasion say much more about the future. The prospects are quite good, in spite of the difficult times through which the industry which we serve, and the country, and indeed the whole world, are passing.

BALLOT FOR THE ELECTION OF MEMBERS AND ASSOCIATES

Mr. T. Dennison (British Iron and Steel Research Association, London) and Dr. H. Lee (Sheffield University), who had been appointed scrutineers of the ballot for the election of Members and Associates, reported that the following 160 Members and 85 Associates had been elected.

Members

Adcock, Joseph Noel (Rotherham); Alborg, Birger Alfons (Imatra, Finland); Baillie, Edmund Stevenson, B.Sc.(London); Baker, Henry, B.Sc.(Eng.) (Kilnhurst, near Rotherham); Bayley, W. R. (Cardiff); Bell, William Claude Elder, A.I.E.E. (Middlesbrough); Bergstrom, Åke R. (Helsinki, Finland); Billingham, Albert, A.R.I.C. (Birmingham); Binstead, *Capt.* Sydney Thomas (London); Blanc, Georges Gaston Jules (Paris); Blegen, Harald (Sauda, Norway); Bradley, Richard Smith, B.S. (Mexico, U.S.A.); Brancker, Albert Victor, Ph.D., B.Sc. (London); Brice, Leslie James, M.Sc. (London); Busby, Ronald (Coventry); Bush, Robert Thomas (London); Cahill, Michael Melvin (Broken Hill, N. Rhodesia); Calvet, Jean (Paris); Carlsson, Carl Georg (Stockholm); Castledine, Walter (Stapleford); Clarke, Percy (Sheffield); Clay, Sir Henry Felix, Bart., M.A., M.I.E.E. (London); Clifford, Sydney Carton, A.I.M. (Coventry); Collis, Charles John Fry, B.Sc. (Hons.Met.) (Swansea); Copley, Thomas Chambers (Thorncliffe, near Sheffield); Cowan, William (Motherwell); Craig, Donald Hugh Cameron, M.I.E.E. (Sheffield); Cravattee, Ernesto (Buenos Aires); Cronk, Harry Cecil (Middlesbrough); Cross, Arthur (Volta Redonda, Brazil); Davenport, Everard (Johannesburg); Davies, Cyril Graham, B.Sc. (Ebbw Vale); Davies, Ernest Henry, A.M.I.Mech.E. (Preston); Davis, William (Benoni, Transvaal); Dewer, James Thomas William A.M.I.Mech.E., M.I.P.E. (Sheffield); Diederichsen, Ernesto George (São Paulo, Brazil); Dolphin, John Howard, A.I.M. (Wolverhampton); Dunn, Joseph Arthur, A.M.I.Mech.E. (Cardiff); Dworjack, Charles Engleberth (Columbia); Edge, Dennis Albert (Birmingham); Eggington, Harold Horace (Brentford); El-Sherif, Ibrahim Mohammed Ibrahim, M.Sc., B.Sc. (Swindon); Ende, Ursula Johanna Christine (London); Ensch, Louis J. (Bello Horizonte, Brazil); Ericsson, Curt (Lulea, Sweden); Eriksson, O. J. (Bofors, Sweden); Errington, Norman (Consett); Feldman, A. Paul, B.Sc. (London); Figiel, Jan (London); Finlay, Walter Leonard, B.S., M.Eng. (Bridgeport, U.S.A.); Fitterer, George Raymond (Pittsburgh, U.S.A.); Forward, Raymond John (Perrivale); Foster, Herbert Ewart (Middlesbrough); Fowler, Ernest Alastair, B.Sc., A.R.I.C. (Greenock); Fullagar, Leo Alfred, B.A., A.M.I.E.E. (London); Gilby, Leonard Charles (Southall); Giustiniani, Piero (Rome); Glover, Thomas James (Cardiff); Goodchild, Norman Lewis (London); Gosling, Robert Starr (Cardiff); Greaves, Frank William (Birmingham); Griffiths, Llewellyn (Shotton); Grönblom, Berndt Gustaf (Helsinki, Finland); Grönblom, Sten (Imatra, Finland); Hardesty, Francis, A.R.I.C., A.I.M. (Newcastle-on-Tyne); Harding, J. V., B.Sc., Ph.D. (London); Harris, Kenneth Gwyther (Cardiff); Heslop, Sydney (Birmingham); Hewett, George Nele (Port Talbot); Hill, William James (Neath); Hilton, John Leslie, O.B.E., M.I.Mech.E. (Chelmsford); Hoffstedt, Hans Bertil Evald (Imatra, Finland); Horák, Jaroslav, Dr.Ing. (Kladno, Czechoslovakia); Hornak, John N. (Munhall, U.S.A.); Horwood, Thomas Baring, L.I.M. (London); Hudson, Aubrey John, M.B.E., B.Sc.(Eng.) (Vereeniging); Hunter, Alexander, B.Sc.(Eng.), A.M.I.E.E. (Rotherham); Hunter, Cuthbert John (Cardiff); Hurrell, George (Stocksbridge); Hutin, Edmond (Paris); Huxley, Walter Richardson (Shotton); Jolly, James Hornby (Smethwick); Jones, Donald Martin (Cardiff); Keefe, Joseph Marsden (London); King, *Eng. Rear-Adml.* Frank Victor, M.I.Mech.E., M.I.Mar.E. (Chesterfield); Kjellman, Ingvald (Abo, Finland); Kowalczyk, Joseph Tomath (London); Kyle, Dennis Hamilton (London); L'Abbate, Saverio V. B. (São Paulo, Brazil); Lahr, Raymond, Dipl.Ing. (Middlesbrough); Lenton, Albert, A.M.I.M.E. (Leeds); Lewis, William Percy (Cardiff); Loewy, Robert (Paris); Longden, Arthur (Rotherham); Lux, Eric, Dipl.Ing. (Pontypridd); Lysaght, Horace James William (Newport); Lysaght, Nicholas Henry Lyster (Newport); McMahon, Louis, B.Sc.(Hons.) (Leeds); Mallett, Thomas George (Shotton); Malmgren, Laurance William, B.Met.Eng. (Granville, Australia); Martin, T. R. (Neath); Mathieson, Roy, B.Sc.(Eng.) (Scunthorpe); May, Eric Borton (London); Meiring, A. P. (Vereeniging); Meyer, Hans Ulrich, Dr.Ing. (Zürich); Miller, J. A. (Buenos Aires); Morley, John Ivan (Sheffield); Nelson, Ferguson Ross, B.Sc., A.I.M. (Coventry); Norsa, Luigi (Milan); Osmond, Walter Percivale, B.A., B.Sc. (Edgware); Pamely-Evans, Owen G., B.Sc., A.R.I.C. (Cardiff); Parker, John Pyne, A.M.I.E.E. (London); Parsons, James Watson, B.Sc. (Sheffield); Paschal, René (Hayange, France); Paschek, F. S. (London); Patrick, Frederick James (Birmingham); Pearson, Dennis (Sheffield); Peech, Alan James (Sheffield); Penna, *Capt.* Antonia Carlos Gonclaves (Volta Redonda, Brazil); Peters, Stephen (Shotton); Podczaski, Brunon (London); Postlethwaite, Roger (Stocksbridge); Prentice, Archibald Graham (Middlesbrough); Ramachandran, Erode Ganapati Iyer, M.Sc. (Bangalore, India); Rexworthy, Desmond Ramsay, A.R.I.C., B.Sc. (London); Rhodes, Edwin Clements, Ph.D., B.Sc., F.R.I.C., F.I.M. (London); Rigby, George William (London); Rodes, Rafail Calvo (Cuatro Vientos, Spain); Rolls, Thomas Burnand, B.A. (London); Rost, Björn Gustav Alexander (Bofors, Sweden); Rotchell, John, A.Met. (Manchester); Royston, Lawrence Kelso, A.Met., A.I.M. (Sheffield); Ruimonte, Florantino Gómez (Madrid); Russell, James Edward, M.A. (Sheffield); Rutherford, Neville Bowman, B.Sc., A.I.M. (London); Santiago, Eusebio Revilla (Madrid); Shepherd, Thomas Thomson, B.Sc.(Eng.) (Motherwell); Simpson, A. H. (Wellington, Shropshire); Smith, Frank Usher (Wolverhampton); Snedden, Andrew (Newport); Stanbridge, Victor Edwin, M.Inst.C.E. (London); Stenfors, Erik (Imatra, Finland); Teed, *Major* Philip Litherland, A.R.S.M. (Weybridge); Thomas, Paul (Alevard, Isère, France); Tomlinson, *Major* Nigel Raymond (Corby); Vann, Alfred Ernest (London); Vinsen, James Goy, B.Sc.(Eng.), A.M.I.E.E. (Newport); Warren, Reginald Ronald (Cardiff); Watkins, Vincent (Sheffield); Wetzel, Jacques (Villerupt, France); Wichman, Ronald Eric (London); Willan, James Henry Gerald (Cardiff); Williams, Cyril, B.Sc.(Hons.Met.) (London); Willoughby, George (Stoke Poges); Wise, Dennis Ambrose, B.Sc. (London); Wolstenholme, Eric (Sheffield); Wright, Cecil Boothroyd (Billingham); Wróbel, S. A., Dipl.Ing., A.R.S.M. (Swindon); Wynne, John Richard, B.Sc.(Hons.) (Corby); Zednik, Vladimir, Eng.Met., D.Sc. (Ostrava, Czechoslovakia).

Associates

Adamson, Kenneth Cecil (London); Allard, Robert William, B.Sc. (Newcastle-on-Tyne); Allen, Eric Sidgwick, B.Sc.(Eng.) (Middlesbrough); Allon, Frederick Rodney Holdroyd (Jarrow-on-Tyne); Bartlett, William Leslie (Cardiff); Bellamy, Roy Graham, B.Sc. (Cardiff); Bennett, Wilson Donald George (Sheffield); Boxall, John M. (London); Bracewell, Richard Henry (Coventry); Bremner, Norman Upton, B.Sc. (Cardiff); Bricknell, R. R. (London); Broadley, John Stewart (Glasgow); Brook, Greville Bertram (Sheffield); Butler, Ronald, B.Met.(Hons.) (Gerrards Cross); Carswell, Ian Liddell (Glasgow); Chatterjee, Pranab Kumar (Sheffield); Cibula, Alec, B.A. (Cambridge); Clark, Peter (London); Cockroft, Maurice George, B.Sc.(Hons.Met.)(Manchester); Codd, Ivor (Scunthorpe); Cook, Peter Mordaunt, B.Sc., A.I.M. (Sheffield); Cowan, Hugh (Motherwell); Crane, John Rupert, B.Sc.(Hons.) (Birmingham); Davis, Leonard Strongnell (London); Delbeke, James P. (Couillet, Belgium); Dennis, Arthur Charles (Sheffield); Denyer, George Douglas, B.Sc.(Hons.Met.) (London); Donaldson, James (Glasgow); Dyball, Herbert Thomas (Birmingham); Edeleanu, Constantin, B.A. (Cambridge); El-Karamany, Mahmoud Fahmy (Cairo); Grieve, Alan (Cardiff); Griffiths, Richard William (Shotton); Gupta,

Bimul Kumar (Calcutta); Harris, Thomas (Motherwell); Harrison, William Douglas (Newcastle-on-Tyne); Head, Michael David (London); Herring, Paul (Croydon); Horsley, G. W., B.A. (Halifax); Howarth, Geoffrey Elmer (Rochdale); Hull, William Griffin, L.I.M. (Langley); Humphreys, David (Romford); James, Edward Lionel (Birmingham); James, Victor Leonard (Portsmouth); Jayes, W. G. (London); Keith, William B. (Glasgow); Lambert, James William, L.I.M. (Thornaby-on-Tees); Linacre, Edward, M.A. (London); Lokier, William John (Swansea); Mack, Kenneth Alexander, B.Sc. (Cardiff); Marles, Douglas (Birmingham); Maslin, Harold George (London); Mincher, Albert Leslie, B.Sc. (Hons.) (London); Moore, Peter Thomas (London); Morgan, Eric Raymond (Birmingham); Narasimhamurty, T. L. (Benares, India); Nortcliffe, John, B.Sc. (Sheffield); Ottley, Derek John (London); Paxton, Harold William, B.Sc.(Hons.Met.) (Manchester); Pow, James (Motherwell); Poyner, Martin Derick Marsh (Walsall); Rowling, Peter J., L.I.M. (Croydon); Sayers, John Brian (London); Sen, Banamali, B.Sc. (Bengal); Shah, Jayant H. (Bombay); Smith, Clifford (Manchester); Som, Kartick Chandra, B.Sc., B.Met. (Burnpur, India); Somerville, James Watt (Glasgow); Steinberg, Morris Albert (Cambridge, U.S.A.); Steiner, Kurt (Wednesbury); Thompson, David Laurance (Stockport); Tolley, Roderick James (London); Tomalin, Peter Frank, B.Sc.(Hons.) (Manchester); Town, Arthur W. (Cambridge); Turner, Donald Howson (Stocksbridge); Upton, John Charles, B.Sc. (Billingham); Van de Weil, Peter Donald (Coventry); Waring, James (Manchester); Warner, John Pelham (London); Watkinson, John Francis (Sheffield); Wattleworth, Clifford Douglas (Scunthorpe); White, Jerónimo Vázouez (Santander, Spain); Williams, David Thomas (Chester); Williams, Edward (Ettingshall, near Wolverhampton); Yeomans, Donald Eric (Birmingham).

PRESENTATION OF PAPERS

The following papers were presented and discussed:

Wednesday, 12th November

Morning Session

"Hydrogen and Transformation Characteristics in Steel," by J. H. Andrew, H. Lee, H. K. Lloyd, and N. Stephenson.

"Hydrogen in Steel Manufacture," by C. Sykes, F.R.S., H. H. Burton, and C. C. Gegg. (*Joint Discussion*).

* "Brittle Fracture in Mild-Steel Plates," by W. Barr and Constance F. Tipper.

* "The Effect of the Manganese-Carbon Ratio on the Brittle Fracture of Mild Steel," by W. Barr and A. J. K. Honeyman.

* "Some Factors Affecting the Notched-Bar Impact Properties of Mild Steel," by W. Barr and A. J. K. Honeyman. (*Joint Discussion*).

Afternoon Session

"A Note on Variations in Producer-Gas Quality," by J. E. de Graaf.

"The Distribution of Fuel in Gas Producers," by M. L. Hughes.

"Experiments on Gas Flow in Producer Fuel Beds," by M. L. Hughes. (*Joint Discussion*).

* "A Photo-Electric Roof Pyrometer for Open-Hearth Furnaces," by T. Land.

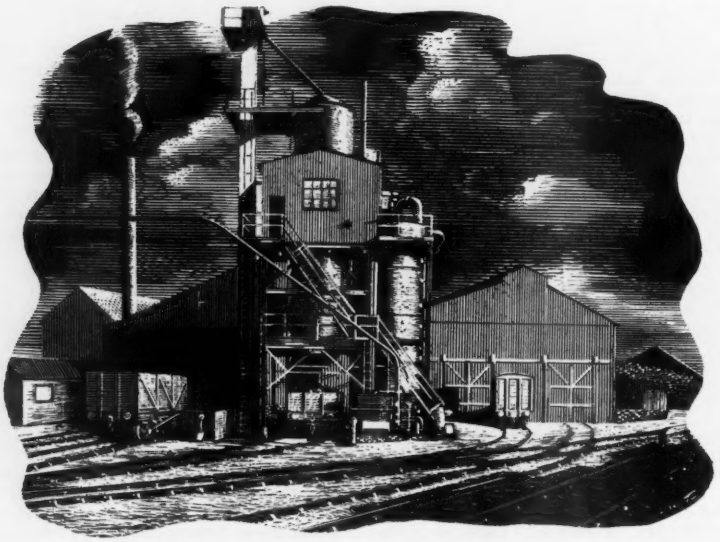
Thursday, 13th November

"The Fluidity of Steel," by R. Jackson, D. Knowles, T. H. M. Middleham, and R. J. Sarjant.

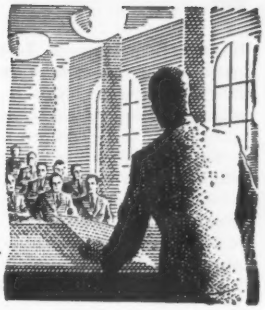
"The Mechanism of Carbon Removal by Oxidation from the Bath in the Open-Hearth Furnace," by A. H. Jay (*deceased*); presented by G. E. Speight.

* "Some Aspects of the Refining of High-Phosphorus Iron," by W. L. Kerlie.

** The discussions on these papers are printed in the following Section, pp. 327–346. The discussions on the remaining papers will be published in the April, 1948, issue of the Journal.*



DISCUSSION ON PAPERS



DISCUSSION AT MEETINGS · WRITTEN CONTRIBUTIONS

Autumn Meeting, 1947

The discussions on five papers presented at the Autumn General Meeting of the Institute in November, 1947, are given below. The discussions on the remaining seven papers will be published in the April issue of the *Journal*.

Discussion on—BRITTLE FRACTURE IN MILD STEEL

Mr. **W. Barr** (Messrs. Colvilles, Ltd., Glasgow) presented for discussion the following three papers:

"Brittle Fracture in Mild-Steel Plates," by W. Barr and Constance F. Tipper.*

"The Effect of the Manganese Carbon Ratio on the Brittle Fracture of Mild Steel," by W. Barr and A. J. K. Honeyman.†

"Some Factors Affecting the Notched-Bar Impact Properties of Mild Steel," by W. Barr and A. J. K. Honeyman.‡

In the course of doing so, he said: Brittle fracture came into prominence during the recent war with the application of welding on a wholesale, mass-production scale in America for the production of merchant shipping. Arising out of the several spectacular failures which occurred, a great deal of work was put in hand in America, and one might have thought from some of the articles in the technical press that brittle fracture in mild steel was a novelty. That, of course, is not so; it has been known in mild steel ever since that material replaced wrought iron.

In this country the failures were more or less isolated, and on nothing like the same scale as in America: it was simply a question of one or two isolated cracks. However, it is only fair to add that our application of welding to ship construction was on a much more limited scale than in America. Nevertheless, the Admiralty Ship Welding Committee thought it worth while to initiate investigations in this country. The great bulk of the work was carried out by Dr. Tipper, under the direction of Professor Baker, in the Engineering Laboratories at Cambridge.

In October, 1945, a Conference was held in Cambridge at which a number of papers were read and discussed, dealing with both the practical and the theoretical aspects of the problem. That conference was held under the auspices of the British Iron and Steel Research Association, the Admiralty Ship Welding Committee, and the British Welding Research Association. A month later, in November, 1945, B.I.S.R.A. asked me to form a small committee or panel to continue these investigations. I suppose that I was asked to undertake this work because I had contributed in a minor way to the Cambridge Conference, and I happened to be a member of the Metallurgy Panel of B.I.S.R.A. The other members of the team were Dr. Tipper, of Cambridge; Dr. Allen, of the National Physical Laboratory; and Dr. Orowan, of Cambridge, and later we were joined by Dr. Slater, of the Admiralty.

Our work was influenced largely by the outcome of the Cambridge Conference. In the first place, it appeared to us to be very desirable to clarify the position with regard to the method of test used in assessing the susceptibility of mild steel to brittle fracture, and that is the subject of the first report, by Barr and Tipper.

The second paper, by Barr and Honeyman, deals with the effect of the manganese carbon ratio on brittle fracture. This paper led the authors to do some further work on notched-bar impact properties, and the third paper, which is an account of this work, has been prepared independently of the above-mentioned committee, the authors accepting sole responsibility therefor.

Mr. Barr then gave a summary of the contents of the three papers.

Dr. **Constance F. Tipper** (Engineering Department, University of Cambridge): Professor Baker was asked to carry out an investigation into the large-scale fractures of mild-steel welded structures by the Admiralty Ship Welding Sub-Committee in 1943. At that time, the fractures which occurred in certain "Liberty" ships were attributed largely to the locked-up stresses due to welding, but Professor Baker himself considered that some check should be made on the quality of the steel being used, while carrying out an investigation into the magnitude of these stresses, and he asked me to take care of that side of the inquiry. In detail, these fractures resembled those obtained in notched impact and static bend tests, but the connection between these small-scale

* *Journal of The Iron and Steel Institute*, 1947, vol. 157, Oct., pp. 223–238.

† *Journal of The Iron and Steel Institute*, 1947 vol. 157, Oct., pp. 239–242.

‡ *Journal of The Iron and Steel Institute*, 1947, vol, 157, Oct., pp. 243–246.

tests and fractures of the magnitude then under investigation was not clear. Moreover, some of the failures had occurred in ships in dock in still water, so that although impact loads might be contributory they did not appear to be essential.

Starting with the idea that a notch was essential, I succeeded in reproducing fractures in the laboratory which had all the characteristics of the "natural" fractures by pulling, in an ordinary tensile testing machine, a strip in which a notch was cut on one edge perpendicular to the direction of loading. If the temperature of the steel were low enough, fracture was always brittle in every plate tested; at higher temperatures the fracture was fibrous. The temperature at which the change from one type to the other occurred varied with the plate, from about − 60° C. up to about + 80° C. By standardizing the dimensions of the strip and notch a very simple form of test-piece was devised which made use of the full plate thickness, an item of considerable importance in testing plate, where the surfaces may differ in structure from the middle.

Up to the beginning of 1945, all the material supplied to me for test had been removed from damaged ships. Then, Sir Andrew McCance and Messrs. Colvilles, Ltd., kindly supplied me with three plates of known history, and following the discussion referred to by Mr. Barr, we started on this systematic investigation. Altogether I have determined the transition temperature of about 40 separate plates, some of them in several conditions of heat-treatment, chiefly by means of notch tensile and Izod tests. I have found differences within one plate, due to structure, heat-treatment, geometry of test-piece, and so on, to be as great as the differences between plates of different compositions. There is very little clear indication that any one element or impurity, other than carbon, is always responsible for raising the transition temperature.

In addition to this investigation, I have devoted considerable time to the study of the initiation and propagation of fractures in mild steel. One may compare the passage of the fracture, starting from a notch, to the successive extension and fracture of a series of tensile test-pieces of very short gauge length, and to the ripping of a piece of material. When the fracture is fibrous, the stress/strain curve from a normal tensile test is a qualitative indication of the behaviour of the material from the beginning of yielding at the bottom of the notch to the formation of the natural crack. Thereafter, the dimensions and shape of the fracture front must be connected, also qualitatively, with the shape of this curve, until a large number of crystals break by cleavage, when conditions change. Thus, stress conditions existing at the initiation of fracture are not the same as those obtaining while the fracture is in progress.

I have never seen a 100% cleavage fracture. Isolated crystals or groups of crystals continue to extend and fracture in a more or less normal manner after the rest have broken by cleavage. It is possible to see this in the microstructure. This accounts for a minute but definite zone of plastic deformation which must be related to the extension of the grain both before and during fracture and which is always visible in the immediate neighbourhood of these fractures. It is for this reason that I prefer to take as my criterion for brittleness the appearance of the fracture together with the elongation across the notch in a notch tensile test rather than some arbitrary figure of energy absorbed in a small-scale impact test.

If fractures such as these can be produced in a given plate at normal working temperatures, I consider that similar fractures are liable to occur in any structure made from such plate, since increase in size tends to raise the transition temperature. The continuity of the welded structure enhances the danger from such fractures, but the problem is fundamentally a material one. This is now generally accepted in the United States and on the Continent; disagreement is chiefly centred on the choice of an acceptable small-scale test and the steps which should be taken to ensure the absence of low-temperature brittleness.

DISCUSSION

Mr. **H. H. Burton** (English Steel Corporation, Ltd., Sheffield): One thing that troubles me in connection with the suggestion put forward by Barr and Honeyman for increasing the manganese content and also the manganese/carbon ratio is that their tests, showing the superiority of these compositions, are based, apparently, on examination of the plate material itself, in other words, the unwelded plate, and particularly on the advantages shown in plates which have received a definite heat-treatment, in this case normalizing. I think that there might be some danger in increasing the manganese content beyond a certain point, when regard is had to the structure developed at the weld, unless that weld is subsequently heat-treated, which I should imagine in the case of ship plate is almost impossible.

Another point is that so far as I can see the only heat-treatment which has been considered—this may be for reasons with which I am not familiar, not being a manufacturer of plates—is normalizing. Those of us who have done a good deal of work on the somewhat higher manganese pearlitic steels (those, say, in which the manganese content is not in the region of 1%, but perhaps up to 1·5%, and which generally give a remarkably good impact test) know that in general a more reliable method than normalizing for increasing the impact value of the steel, which perhaps through a hot finishing treatment is deficient in impact strength, is tempering. I know of cases where in the original as-rolled condition the impact strength of such a steel has been 6–7 ft. lb., and where after tempering at 600° C. it has been 100 ft. lb. There is the further advantage of producing a plate which is more free from internal stress than one which has been normalized.

Again, it is necessary to take into consideration that even if you produce a plate so heat-treated which has in itself good properties, the properties of the weld, which cannot be subsequently refined, may be quite bad. I wonder, therefore, whether the direction in which we might seek for something along the lines indicated by Dr. Tipper might be by the addition of some element which would tend to inhibit grain growth, and also inhibit air-hardening tendencies.

Turning to the papers by Barr and Honeyman, I heartily agree with what they say about the effect of increasing the manganese/carbon ratio in the way that they have done. In general, it is possible to obtain in this way very much better properties in the steel. I suggest that a still greater improvement will be obtained by a further increase in the manganese/carbon ratio, aiming at something of the order of 0·10–0·15% carbon and 1·5–1·7% of manganese.

Dr. **I. G. Slater** (British Admiralty Delegation, Washington): I should like first to reiterate a remark which Mr. Barr made about the history of brittle fracture. Certainly the experience in America with the "Liberty" and other ships which suffered brittle fracture has "triggered off" an enormous amount of work on both sides of the Atlantic, but we should always remember that these phenomena have long been familiar,

as in history-book illustrations of our earlier armaments in active use.

With regard to the work now going on in America, it may be useful to mention one or two of the more important matters which are now being considered. Perhaps one of the most interesting facts is the magnitude and scope of the investigations which are engaging the attention of metallurgists, engineers, and physicists. Quite recently a most useful seminar was held by the American Society for Metals at Chicago, when some two dozen papers dealing with fundamental relationships in the fracturing of metals were read and discussed. I would commend these papers, which I hope will be published shortly, to all who are interested in these matters. In addition, only about two weeks ago a number of papers were read at the autumn meeting of the American Welding Society, which are of very immediate interest. To summarize the American outlook and the progress of their work, I think that it is fair to say that their views are certainly a long way from being crystallized, and it is very obvious that we have a long path to take yet before we reach any degree of finality. Perhaps the most striking feature which has emerged is the inadequacy of our previously standardized methods of test, especially in the exploration of properties outside the elastic range. This problem of finding a suitable small test-piece to evaluate relative brittleness is certainly a difficult one, and we are by no means near finality, I feel, in the several test methods which the authors have outlined.

In this connection, I think that it is most profitable to examine in some detail instances of brittle fractures which have occurred in service ; and it might be useful if I outline a few which I have come across which are other than in ship's plating. Examples are such structures or components as boiler drums, chain links, forgings, studs, and bolts. As regards composition, many of the steels which have failed in a brittle manner have had carbon/manganese ratios substantially greater than 1/3. They were all of the inherently coarse-grain variety. Significant features in these failures include such phenomena as the presence of stress raisers of considerable magnitude (such as a crack or deep corrosion pit or slag inclusion), sharp corners, screw threads, and the like, and all the failures occurred at lower temperatures, for example, during winter weather. Additionally, an energizer of some description or other was evident which set off the rupture. Another significant feature has been the presence of strain-age embrittlement of the steel in an area adjacent to the origin of fracture. The overall significance of each of these several features must be integrated, possibly with others which I have not mentioned, in order to arrive at a satisfactory basis for the comparison of mild steel. I feel strongly that this matter is not a simple one involving only a limited number of properties in the steel, but is the integration of a large number of properties.

Finally, I should like to have the views of the authors on the significance of the width of the temperature range over which the fracture of the steel changes from tough to brittle. These temperature ranges may vary in width ; I have seen them quoted as much as 100° C., and very often they vary according to the method of testing employed. Is this temperature range related to the depth of metal affected in a plastic manner immediately adjacent to the fracture ?

Dr. **N. P. Allen** (National Physical Laboratory) : These are reports of an investigation which is in a preliminary stage. A great deal of work will be necessary before a full understanding of the phenomena of brittle fracture will be obtained, and what Mr. Barr and Mr. Honeyman have to say is that while the work necessary to elucidate these problems is going on it will be well to keep the manganese content of the steel up and the carbon content down.

The investigation has gone into the effect of composition to some extent, dealing with manganese and carbon, and the effect of rate of cooling, and the rate of cooling is found to be important. Manganese makes the material less sensitive to slow rates of cooling, but the point which it is essential to emphasize is that we do not know yet what is the range of temperature over which the rate of cooling is important.

Plate steel as a rule is left as rolled, and variations in it are most likely to be due to variations of the finishing temperature of rolling and of the cooling rate ; but the cooling rate that is likely to vary is the cooling rate in a relatively low range of temperature, round 400° C., where such accidents as the precise position where the plate has been put down on the floor have an opportunity to make their effects felt.

When we consider from a metallographic point of view what changes might be effected by alterations of the rate of cooling, we think at once of the critical changes ; but it is well to remember that when the critical changes are over the ferrite in the material is not in its final condition. It contains more than it will contain when cold of certain impurities in solid solution—carbon, nitrogen, and so on—and in cooling from 600° C. downwards a second series of changes will occur, which may well be quite as important as the critical changes occurring at temperatures round about 800° C.–600° C. The microstructures published in these papers show that on the whole the changes occurring in the critical range are not likely to be the important ones, because it is not difficult to pick out steels with exactly the same microstructure but very different temperatures of transition from tough to brittle fracture.

The difficulty of studying the precipitations from the ferrite between 600° C. and room temperature, which may very reasonably be the cause of some of these troubles, is that hitherto we have not been able to detect microscopically the very small particles which presumably come out of solution ; but although we have been labouring under that difficulty for a very long time, the progress in microscopic work at high magnifications is such that there is reasonable hope that the range of useful magnifications available in metallography will increase to at least × 10,000, and it will be possible to see particles which are not more than 100 or 200 rows of atoms across.

Mr. **W. E. Lewis** (Lloyd's Register of Shipping, Glasgow) : The authors are to be complimented upon the valuable contributions they have made towards an understanding of some of the factors which can affect the notch sensitivity of mild structural steels and lead to their sudden failure, in service, through brittle fracture. No one can logically criticize the experimental data presented nor, in general, can one challenge the conclusions drawn from such data. To me the value of such researches into the action of industrially destructive influences lies in the recommendations that can be made to prevent or, at least, to mitigate the destructive action. Should it be possible to translate such recommendations into a specification, their value would be considerably enhanced.

Two distinct recommendations of this nature have been made in these papers, the first being to determine the notch-sensitivity of the structural steel by the rupture of a notched test-bar.

In Table VIII of the paper by Barr and Tipper are

set out the limiting temperatures of the change from fibrous to cleavage fracture as determined by three different methods of notched-bar testing. It will be observed that while each type of test places the different steels in, roughly, the same relative order, a change in the form of the test-piece is accompanied by a change in the limits of the transition range. In the second of their two papers Barr and Honeyman state that it had not been possible to determine quantitative values for notch sensitivity and that only a qualitative comparison under arbitrary test conditions could be made between different steels. If this is indicative of our present state of knowledge in respect of the notch sensitivity of a steel, I, personally, should hesitate to accept a notched-bar test as a criterion of the suitability for service of structural mild steel. It is suggested that a great deal of the disagreement that now exists in respect of the value of the notched-bar test could be eliminated by the universal adoption of one, agreed, standard form.

The second proposal submitted in the papers is to ensure that the ratio of manganese to carbon should not be less than 3.

With the exception of two anomalous cases, referred to later, satisfactory evidence is presented that, for plates of equivalent tensile strength, of the same thickness, and subjected to the same heat-treatment, increase in the manganese/carbon ratio leads to a decrease in the transition range for a given type of notched test-bar. Support for this is afforded by the results of tests, on plates 6 ft. wide, carried out in the United States. In view of the selection of 3 as the minimum value of the manganese/carbon ratio, the Society of Lloyd's Register collected information in respect of heavy steel plates rolled in Britain and suitable for building into classed vessels. Of 700 casts investigated, 93% had a ratio of 3 and over, the ratio of the remainder being between 2·7 and 3. As little trouble has been encountered to date in welded ships built of British steel, I consider that this recommendation is worthy of consideration.

The two anomalous cases mentioned above are steels *D*1 and 1229, which have a Mn/C ratio of 1·5, and steels *E*1 and 1278 with a ratio of approximately 7. In each of these pairs the difference in the notched-test characteristics is striking and I would welcome further comment by the authors upon such discrepancies.

As the thicker plates in a ship's hull are, in general, situated in the most important and highly stressed localities, the authors' discovery that, all other factors being constant, increase in the thickness of a plate increases the notch sensitivity of the material is somewhat disconcerting. It would appear therefore, that it would be advantageous to use in these localities, at least, a material corresponding to the special quality of steel for shipbuilding specified by Lloyd's Register. This has a manganese/carbon ratio of 3 and, being required by specification to have a minimum limit of proportionality of 15 tons/sq. in., advantage can be taken of a reduction in scantlings which would help to mitigate the effect of thickness. A further reduction of risk could be effected by normalizing the thicker plates of this type of steel. Could the authors please comment upon the industrial aspect of this suggestion ?

Mr. **J. Rosen** (Department of Aeronautical and Engineering Research, Admiralty) : Sir Amos Ayre, of the Shipbuilding Conference, regrets that he is not able to be present, but, as I am associated with this work, he has asked me to present certain notes of his to this meeting. He writes :

It is a keen disappointment to me that I am unable to be present at your discussions on this matter of brittle fracture in mild-steel plates, particularly since as Chairman of the Admiralty Ship Welding Committee it has fallen to my lot to follow these investigations with great interest. The importance of notch brittleness as a factor in the fractures of welded ships, with which our Committee has been primarily concerned, was brought home to us originally by Professor Baker as the result of the investigations carried out for us by Dr. Tipper at Cambridge. We are very much indebted to Dr. Tipper for this important pointer, and also to Mr. Barr and his associates for their patient work in helping us to elucidate and guard against it.

Whilst our Committee is naturally most anxious to arrive at a complete solution of the problem, we realize that we must be patient while the researches are going on ; but in the meantime we have reached the view that for shipbuilding steel of normal thicknesses the manganese content should be three times the carbon content. This is in fact in accordance with Mr. Barr's proposal, which we understand is generally in line with current British steelmaking practice. If applied with reasonable tolerance, therefore, the recommendation should not entail any increase in cost to the consumer.

Whilst we feel that this will afford a great measure of protection against brittle fractures in service, we sincerely trust that the investigations will be pursued unflaggingly towards the complete elucidation of the problem.

Mr. **J. N. Bradley** (Royal Naval Scientific Service, Emsworth, Hants.) : I have been interested in the question of brittle fractures in mild-steel plates for some time, and I should like to add some information which supports the contention of Barr and Honeyman regarding the beneficial effect of manganese on the transition temperature. Recently we have been doing some experiments which involved the determination of the transition temperature on four steels, the analyses of which are shown below in Table A:

Table A

CHEMICAL COMPOSITION OF STEELS *P*, *Q*, *R*, AND *S*

Steel	Chemical Analysis.									Mn/C Ratio
	C, %	Si, %	S, %	P, %	Mn, %	Ni, %	Cr, %	Mo, %	Cu, %	
P	0·25	0·14	0·050	0·027	0·58	0·18	0·05	...	0·10	2·3
Q	0·23	0·16	0·045	0·025	0·56	0·18	0·06	...	0·09	2·4
R	0·22	0·19	0·025	0·035	1·62	0·06	0·04	0·06	...	7·4
S	0·20	0·18	0·025	0·034	1·61	0·07	0·05	0·06	...	8·0

Table B

MECHANICAL PROPERTIES AND TRANSITION RANGES OF STEELS *P*, *Q*, *R*, AND *S*, NORMALIZED

Steel	A.S.T.M. (McQuaid-Ehn) Grain-Size	Mn/C Ratio	Mechanical Properties.			Transition-Temperature Range, °C.
			Ultimate Tensile Strength, tons/sq. in.	Elongation on 4 $\sqrt{\text{Area}}$, %	Reduction of Area, %	
P	5–7	2·3	34·4	26	62	−20 to −25
Q	2–3	2·4	33·4	31	61	+20 to −10
R	2–4	7·4	40·8	28	69	−20 to −30
S	6–8	8·0	38·3	30	61	−20 to −40

P and *Q* normalized at 920° C. *R* and *S* normalized at 870° C.

The above steels are deoxidized with silicon ; they are similar in this respect to the authors' steels. The residual elements are rather higher, but in other respects the steels are complementary to those of the authors. Steels *P* and *Q*, and *R* and *S*, differ only in composition and manufacture by the fact that *P* and *S* were finally deoxidized with aluminium to render them of fine inherent grain-size. The mechanical properties and transition-temperature range on the normalized steels are shown below in Table B.

The transition temperature was determined on B.S.I. Charpy specimens broken by slow bending. It will be noticed that (i) aluminium deoxidation has improved the transition temperature in the case of the mild steels *P* and *Q*, but has a lesser effect in the case of the higher-manganese steels *R* and *S*, and (ii) the beneficial effect of the higher manganese content is apparent and the coarse-grained steel *R* is fully equal to the fine-grained mild steel, *P*. These results are in general agreement with those of the authors.

The authors seem to have concentrated on the practical rather than the fundamental approach to the problem of brittle fractures in mild steel. I feel, however, that even in this connection factors of importance are in danger of being overlooked. Brittle fractures in mild steel came into prominence when welding began to be largely used in ship construction, and yet little attention has been given to the effect on the transition temperature of sub-critical quenching followed by ageing, which may well occur in the neighbourhood of welds. Have the authors any information on the relative susceptibilities of high- and low-manganese steels in this respect, and is there a difference in their strain-ageing characteristics ?

The authors tend to discount the importance of assessing the relative merits of mild-steel plates by their fracture in the notched-bar test. Whilst I feel that it is well established that plastic strain during testing does not prejudice the formation of a cleavage fracture, autographic records from notched-bar and notched tensile tests clearly show that an actual fracture by cleavage is accompanied by negligible strain. In the circumstances, an assurance of the material's ability to resist crack propagation is afforded by the appearance of the fracture. It is surely just as important to ensure that a crack if propagated does not spread in a catastrophic manner as it is to ensure resistance to the initiation of a crack.

Mr. **G. M. Boyd** (Lloyd's Register of Shipping, London) : In the second paper by Barr and Honeyman, in the last sentence of the synopsis and on p. 245, the authors suggest that resistance to the initiation of a fracture is of greater practical importance than the resistance to propagation. While this argument has considerable cogency, on the grounds that resistance to propagation is like closing the stable door after the horse has bolted, or in other words, if we can prevent fractures from starting we need not worry about how easily they would have progressed if they had started, there is another side to the picture.

The argument the authors have made relies on the supposition that fractures can in fact be prevented from starting, and it is interesting to examine this supposition.

An incipient fracture may be regarded as a very sharp notch and conversely a notch may be regarded as an incipient fracture, which may, however, have any degree of sharpness. Now, as the authors have themselves remarked, notches of some form or other are always liable to be present ; in fact, one might say extremely liable. Good design and workmanship can minimize the number and severity of notch effects, but they cannot prevent accidental notch effects such as the hair cracks which seem to be an inevitable concomitant of sheared and even planed or flame-cut edges, the occasional small cracks or defects which are almost inseparable from welding, and occasional inherent cracks or other defects in the steel itself. In addition, cracks due to stress corrosion and fatigue are always likely to develop.

We must, therefore, face up to the fact that notch effects or incipient cracks are practically inevitable even with the best of design, material, and workmanship. This being the case, the resistance to further development of the cracks becomes of paramount interest, and resistance to initiation falls into second place.

The authors appear to imply that if the notch effect is sufficiently severe, as in the case of an incipient crack, brittle fracture is inevitable. There is, however, considerable experimental evidence against this. For example, fractures have been artificially initiated by fatigue and otherwise, and when pulled in a tensile machine these fractures have progressed in the shear, or fibrous, mode whenever the temperature was above the transition temperature for the steel, as ascertained by notch impact or notch tensile tests.

There is very considerable evidence to support the view that it is, in fact, the resistance to propagation as distinct from resistance to initiation of cracks which distinguishes ductile steel from notch-brittle steel.

The ordinary notch impact test cannot, without special equipment, separate the energy of initiation from the energy of propagation, but with the notch-bend type of test the separation is comparatively simple. The authors argue from the fact that both tests place the steels in the same order of merit, that the notch impact test is a convenient measure of the notch sensitivity on the basis of energy of initiation. This deduction overlooks the possibility that while the energy of initiation may not vary greatly with temperature, the energy of propagation may depend very much on temperature. The two energies may also depend differently on speed of loading, and on the sharpness of the notch. I do not know what research has been done in this country on the dependence of the two energies on these variables, but until the results of such research are available it may be well to proceed with some caution. If it is found that resistance to initiation does not vary much with temperature, it cannot be accepted as a criterion, since it is known that the actual service performance varies very greatly with temperature.

It seems to be well established that the most important criterion for distinguishing between steels on the basis of their liability to brittle fracture in service is the transition temperature, as defined on p. 223 of the October, 1947, *Journal*. It is known that the transition temperature depends on rate of loading, on the shape of the notch, and on the form of loading. If we could standardize the rate and form of loading and the shape of notch, it would not greatly matter what standard were adopted, although service conditions should be simulated as nearly as possible, and we would be able to assign a definite "standard" transition temperature to each steel.

It is not suggested that the transition temperature should be ascertained as a matter of routine, but by means of a single notch impact test, or notch tensile test, made at a standard temperature, it would be possible to ascertain whether the transition temperature were above or below the standard test temperature.

The assessment of a maximum permissible standard transition temperature would, of course, be a matter for technical judgment and compromise, but it is suggested that the maximum be set at a level which would reject only a very small proportion of British shipbuilding steels, which have proved on the whole to be entirely satisfactory in service.

Dr. **S. A. Main** (Messrs. Hadfields, Ltd.): The Cambridge Conference of which you have heard came to what I thought was the rather unwarrantable conclusion that the quality of the steel was mainly responsible for the catastrophic failures of plates in American ships. While it is true that the steel in those ships was in some cases not all it might have been, the evidence provided in other ways showed, to my mind, that adverse factors of design and methods of construction could have had equally as much, if not more, responsibility for those failures. Those factors were too readily minimized at that Conference.

I need not go into the details now, because what I have said is already on record; but I will put it in this way, that if in the construction of a ship, or any other structure, you tie up the steel and seriously restrict its possibilities for displaying its ductility, how can it be expected, when it does fail, to give anything but a brittle fracture? It is possible in the laboratory, by using the right means, to put a brittle fracture into the best of mild steel. At the conclusion of the Conference in question it was stated that those factors of construction were being investigated so far as they could explain the American failures, and it will be useful to know in due course, if the enquiries have not already been completed, what results have been obtained from those investigations.

Since we have been told that there has been no trouble at all to speak of in British ships, I cannot see how this work which has been put in hand on British ship plates can go very far to explain the American trouble. The authors have, however, rightly ignored these practical questions and have tried to find out the metallurgical factors which will give a high Izod value at low temperatures. That is all to the good, and their success will be welcomed if it leads to the improvement not only of ship plates but of plates for other purposes. It should also provide some additional margin, if that is necessary, in the construction of British ships; but can it be said that any standard which could be devised out of the authors' work in the form of an Izod test or any other impact test or notch test could be a sufficient safeguard against all the possibilities in the power of the ship constructor, so far as encouraging brittle fractures is concerned, in his designs and in the methods and care which he employs to fabricate his ships?

With regard to the paper by Barr and Tipper, I have only one point of mild criticism, and that is the introduction of the broken plate *Z* in Fig. 59 on p. 237. That seems to be rather an interloper in an otherwise highly systematic investigation. It is quite clear that the steel is not up to our standards, but by itself the information is capable of dangerous inferences. Were the adjoining plates, or any of them, similarly found broken? If not, or if there has been no opportunity of getting to know, then as they were probably of the same quality, I think it is quite fair to reserve the opinion that structural factors were at least as much at fault as the steel.

The **President** (Dr. C. H. Desch, F.R.S.): I wonder how many people remember the time when this problem came up thirty years or more ago? There was a case then of a vessel on the stocks which in the course of construction split through the whole length through the rivet holes. The line of plates was taken out and replaced by another, and the same thing happened again. In each case the night was very cold. That was investigated by a number of us, and I remember that the manganese in that steel was exceptionally low. An interesting point about it was that the vessel in question was being built as an ice-breaker for the Baltic.

CORRESPONDENCE

Mr. **D. McLean** (National Physical Laboratory, Teddington) wrote: One of the most interesting points brought out by these papers is that the tough-to-brittle transition temperature is raised by slow cooling. It seems permissible to interpret this as meaning that the transition temperature is raised by carrying equilibrium conditions in the steel to lower temperatures so that any changes taking place can go further to completion. Although no single result supports this interpretation unequivocally, since with all of the changes in experimental conditions the authors use which affect the rate of cooling, other factors such as grain-size are affected as well, yet with, I think, only one exceptional result, every change which reduces the rate of cooling—annealing compared with normalizing, using thicker plates, or increasing the normalizing temperature—raises the transition temperature. This behaviour of mild steel is similar to that of temper-brittle alloy steels, in which also heat-treatments that promote equilibrium corresponding to temperatures below about 650° C. raise the

tough-to-brittle transition temperature. Since alloy steels are not normalized but quenched and tempered the effect manifests itself with them in practice in that the transition temperature is raised by slow cooling from tempering or by tempering at reduced temperatures. The authors do include a few results on quenched and tempered specimens of their carbon steels, and it would be interesting to see them extended, since in this way it is possible to separate the changes in equilibrium conditions from, for instance, changes in grain-size. Bearing in mind that the curves of impact strength against testing temperature have the same general shape for carbon steel, alloy steel, and iron, it seems almost certain that the two phenomena are simply two aspects of the general question of the tough-to-brittle transition in ferrite and its dependence on heat-treatment and composition.

If this is so, the authors' results raise an interesting point in connection with temper-brittleness. They suggest that the problem has been wrongly posed, at any rate as far as the mechanism of embrittlement is concerned. The question usually asked about temper-brittleness is "Why is material brittle when slowly cooled from tempering?" However, examination of curves of impact value against testing temperature shows for alloy steels in general that material slowly cooled from tempering has a transition temperature roughly in the same region as the authors' mild steels, but material quenched from tempering has a much lower transition temperature. There are exceptions to these statements, but they represent the general result. So by and large it is the quenched material, not the slowly cooled material that differs from normalized or annealed mild steel, and the question asked should be "Do alloy elements make quenched material tough, and if so, why?" This may well be an easier question to answer.

The authors describe their brittle fractures as cleavage fractures, but appear to have examined them at a magnification of only six times. With steels of the usual run of grain-sizes it is very doubtful indeed if one can distinguish between a genuine intergranular fracture and a cleavage fracture at this magnification. With alloy steels, the brittle fracture seems to be sometimes intergranular and sometimes cleavage; may not the same thing happen with mild steel? I would also ask if the authors use the term cleavage plane in the sense of a crystallographic plane of definite indices, or simply to mean a flat, presumably transcrystalline, facet on the fracture.

In connection with the authors' conclusion in favour of a manganese/carbon ratio, it is interesting to recall that Greaves and Jones in their well-known work on susceptibility towards temper-brittleness* found that manganese increased the susceptibility ratio of 0·35–0·4% plain carbon, as well as alloy steels. They did not of course actually determine the transition temperature, but their results lead to the conclusion that it is not progressively lowered by manganese for all heat-treatment conditions. In the slowly cooled from tempering condition it appears on the contrary to be progressively raised.

Monsieur **Henri M. Schnadt** (Brussels, Belgium) wrote: The papers by Barr, Tipper, and Honeyman form a very interesting experimental contribution on the influence of temperature and of certain steelmaking factors on the tendency to brittle fracture in mild steels, and the authors are to be congratulated. The investigation tends, nevertheless, rather to demonstrate facts than to explain them; hence, from this point of view the papers do not contain anything essentially new, capable of throwing a little light on the mystery which so far has always surrounded the mechanism itself of impact tests and in general the phenomena of deformation and rupture of metals and particularly of steels.

The researches carried out by the writer for some years have enabled a corner of the curtain to be lifted and have yielded a very simple explanation of the reason for fractures without plastic deformation in steels and other phenomena more or less closely related, such as the behaviour of steels under impact and the influence of temperature on their plasticity and toughness.

It seemed to the writer that these papers might give him the opportunity to outline the new theories by showing their application to the subjects dealt with by the authors. As space does not permit of their treatment in detail, the writer apologizes in advance for the very sketchy character of what follows.

The writer was able to show that if a steel, not cold-worked, were stressed above the elastic limit at a given temperature t and rate of deformation v, it could be plastic at the points considered only if the parameter $\Omega_{tv} = \pi - \phi^s_{tv} > 0$; in this plastic condition π represents the "plastifying work"* of the stresses, and ϕ^s_{tv} the intrinsic brittleness of the metal for the given values of t and v. The characteristics π and ϕ^s_{tv} are non-dimensional.

The "plastifying power" π depends on the multi-axiality of the stresses and can vary from zero to 2; it is equal to 1 in uni-axial stresses, to zero in isotropic tri-axial stresses, and to $\sqrt{3}$ in pure torsion. In an experiment, therefore, it depends on the shape and dimensions of the specimen and also on the mode of stressing.

The intrinsic brittleness ϕ^s_{tv} increases if v increases and particularly if t decreases, but it is completely independent of the stresses and of their degree of multi-axiality.

If, then, in a test the intrinsic brittleness ϕ^s_{tv} of the steel and the "plastifying power" π of the stresses are such that the parameter $\Omega_{tv} = \pi - \phi^s_{tv} \leq 0$, the steel fractures without plastic deformation, *i.e.*, like glass. This occurs the more readily the lower the value of π (notched specimens) and the higher the value of ϕ^s_{tv} (reduction of temperature and impact stressing).

For this reason there is for each steel a temperature (called "critical" by the writer) below which it will break like glass without absorbing energy. This temperature obviously depends on the type of test, because the greater the π value of the test stresses the lower is the corresponding critical temperature of the steel. If the testing temperature exceeds the critical temperature of the steel for the type of test in question, the parameter Ω_{tv} becomes positive and plasticity or toughness appears.

But it can be shown that even in the plastic condition cleavage fracture can occur so long as the parameter of rupture Ω_{tv} is below the limit of indirect cleavage δ_{Rtv} of the steel and that shear fracture appears only when $\Omega_{tv} > \delta_{Rtv}$. This condition of absence of cleavage results quite simply from the basic diagram for steel, showing graphically and very simply its elastic, plastic, and breaking behaviour for all states of stress.

The shape of the toughness/temperature curves and the corresponding appearance of the fracture sections obtained by the authors immediately becomes obvious. In particular, the lower the limit of indirect cleavage

* *Journal of The Iron and Steel Institute*, 1925, No. I, p. 231A.

* *Pouvoir plastifiant*, the ability to confer the property of plasticity.

fracture of the steel, the more rapidly does the transition occur on passing the critical temperature.

According to the new theories, the plastic quality of a homogeneous steel that has not been cold-worked is completely defined by its intrinsic brittleness ϕ_{tv}° and not by the result of a given fracture test, for such a result does not depend directly on ϕ_{tv}°, but solely on the parameter $\Omega_{tv} = \pi - \phi_{tv}^{\circ}$. Hence the plastic behaviour shown in a test is translatable into practice only if the "plastifying powers" π of the test stresses and of the service stresses are identical. That is very important, because if, for example, the π value of the service stresses were less than that of the test stresses it would be possible for a steel which had been perfectly plastic under test to break like glass when forming part of a structure. This is precisely what occurred in several accidents that happened to welded bridges and ships ; in this way these mishaps are easily explained and are no longer mysterious.

In order to have a complete picture of the ability of a steel to deform plastically it is necessary, therefore, to test it under stresses with widely varying values of π and ranging particularly over the lowest values of π in industry. This led the writer to develop a new method of impact testing for steels and other materials, based on a new type of specimen, very simply prepared, and which can be applied much more widely than the Charpy, Izod, and other specimens of the same type.

This new specimen permits the steels under test to be submitted to tensile stresses with given plastifying powers, but varying from one test to another as follows :

Test for :

Dynacity, K_4, with $\pi_4 = 0{\cdot}866$.
Polatopy, K_1, with $\pi_1 = 0{\cdot}55$ approximately.
Coheracy, K_0, with $\pi_0 = 0{\cdot}40$ approximately.
K_4, K_1, and K_0 are measured in kg.m./sq. cm.

The corresponding stresses are called dynacic, polatopic and coheracic ; the dynacic stresses are those most usually encountered industrially and are the least severe, whilst the coheracic stresses are the most dangerous and exist, for example, at the bottom of even a natural fissure in a piece of metal.

The effect of the factors capable of causing ϕ_{tv}° to vary should equally be revealed by means of these tests. This has led the writer to speak of, for example, dynacic, polatopic, and coheracic ageing, of dynacic, polatopic, and coheracic "weldductancy"* and to define the influence of temperature by three curves giving the variation of the dynacity, polatopy, and coheracy as a function of temperature. This influence cannot be determined exactly as the authors have done. In particular, each steel has three critical temperatures of interest, namely, those of dynacity, of polatopy, and of coheracy, the latter being the highest.

From the constructional viewpoint the new testing method renders quite superfluous the carrying out of tests at temperatures below the lowest at which the steel will be used. To know the tendency of a steel to give brittle fractures it is sufficient in all cases to determine its coheracy K_0 for the lowest temperature at which it will be used. If the steel has the property of coheracy it will not be possible for a crack to be propagated nor, *a fortiori*, to start.

The curious phenomenon of the brittleness of steels due to shape is equally easily explained, and it can be shown that all steels suffer from it except those that possess coheracy and those that have no dynacity. Care must be taken, nevertheless, not to confuse this cause of brittleness with the often much greater brittleness of thick pieces due simply to an increase in ϕ_{tv}° inherent in the method of shaping rolled steels.

To close this discussion a few particular comments will be made :

(*a*) The authors conclude that there is a fairly uniform relation between the ratio Mn/C and the so-called "transition" temperature of the steels examined, the latter diminishing with increasing Mn/C. That, however, would seem to be not always the case, because the following figures for the normalized steels may be extracted from Table VI (p. 245) :

Mn/C	3	3·9	4	4·7
Transition temperature, °C.:				
Normalized	−25	+10	−25	0
Annealed	+30	+60	+50	+45

If, as the writer's own experiments confirm, manganese has a good effect and at the same time carbon has a bad influence, their combined action is not expressed by the ratio Mn/C.

(*b*) At the end of the first column on p. 242 the authors attribute the greater impact value of certain steels to "the increased ductility of these steels as shown by the elongation and reduction of area in the tensile tests." That is not quite correct, because there is no exact relation between the two figures, seeing that they each relate to plastic deformations effected under clearly different "plastifying powers" π.

(*c*) As a conclusion the authors, at the end of p. 242, recommend that for the acceptance of ships' plates a minimum value of 3 for the Mn/C ratio should be prescribed. The writer thinks, however, that such a requirement, being additional to those already in force concerning the chemical composition, tends to put aside still further the question of the constructional value of these plates in use. Tests which the writer has made on dozens of steels of all sorts have in effect shown that the chemical composition of a steel is a very uncertain means of imparting to the steel the properties necessary to ensure the stability of the welded structure of which it is to be a part ; for these properties are of a mechanical nature, and it is better to impart them direct, with the aid of appropriate mechanical tests (already in existence) than by a roundabout means without guarantee of success. For his part, the writer prefers to travel in a ship of which the steel contains 0·05% of sulphur and 0·05% of phosphorus with a coheracy of 7 kg.m./sq. cm. rather than in a welded ship of which the steel, with 0·2% of sulphur and 0·02% of phosphorus, would be excessively clean but might have a coheracy of only 0·4 kg.m./sq. cm. In the former one could feel certain that there would be no mishap due to the steel, even though its sulphur and phosphorus contents were higher.

AUTHORS' REPLIES

Mr. **A. J. K. Honeyman** (Messrs. Colvilles Ltd., Glasgow), replying to the discussion, said : On behalf of Mr. Barr and myself, I should like to thank the many contributors to the discussion for what they have said. As the time allotted for discussion has already been exceeded, I shall reply in writing, but there are two points to which I would refer briefly. First of all there is no practical metallurgical problem so far as brittle fracture is concerned. By water quenching and tempering mild steel it is possible to reduce the transition range to well below 0° C. but the cost of such treatment would be prohibitive. Thus, the problem is economic and not metallurgical. What we set out to do was to give shipbuilders a practical suggestion which would reduce, not completely eliminate, the incidence of these sudden fractures in steel *without increasing the cost*. Mild-steel

* "Weldductancy" is the toughness of the heat-affected zone adjacent to the weld subsequent to welding.

plate such as is used for shipbuilding, over $\frac{1}{2}$ in. thick, if it breaks at all in the presence of a notch, will break with a brittle fracture. What is necessary is to prevent a crack taking place. That can be done by decreasing the notch sensitivity and a cheap method of doing this is by increasing the manganese/carbon ratio.

With regard to strain ageing of steels, all mild steels have their transition range raised by strain ageing and so far as we can see the raising of the transition range by straining 10% and ageing at 250° C. is much the same for all steels. Thus, the lower the transition range one starts with, the less dangerous is the effect of strain ageing.

Dr. **C. F. Tipper** (Engineering Department, Cambridge University), in reply, wrote : The significance of the extent of the temperature transition range is not yet altogether clear. It is partly connected with the geometry of the test-piece as Fig. 37 shows, where reduction in thickness closes the range. It is also partly due to the structure of the steel, *i.e.*, degree of lamination and character and distribution of slag inclusions, since plates and test-pieces of the same thickness show great differences in the extent of the range, *cf.* specimens Nos. *A*1 and *E*1, in both Izod and notch tensile tests. It is, in my opinion, related to the shape of the natural fracture front which depends on both of the factors mentioned above as well as on the temperature and on the ductility at the temperature of test. It is probable that with wider test-pieces having a single notch, there would be no such "range." Starting at the lowest temperatures where the fibrous zone at the notch bottom is very small, this zone would increase in size as the temperature was raised until the whole fracture became of the fibrous type. It seems likely that the upper limit of the range in both Izod and notch tensile tests most nearly represents the temperature at which brittle fractures may be initiated in plates of large dimensions. This is confirmed by tests on wider samples.

Dr. Allen and Mr. McClean both refer to the influence of rate of cooling below the critical range on the incidence of brittleness, but from somewhat different aspects. Both are capable of experimental investigation. There is one essential difference between temper brittleness and "cold" brittleness ; the former is permanent, the latter is transient. Therefore, it appears unlikely that the brittleness is caused by the same factor, although I agree that in both instances it is related to the tough-to-brittle transition in the ferrite.

A more detailed investigation of the fractures, an account of which is now being printed by H.M. Stationery Office, has shown that a large proportion of the fractures are in fact cleavage, although some crystals deform and fracture in shear. X-ray analysis on large crystals fractured at low temperatures has also confirmed that the planes of fracture are parallel with the cube faces of the crystal. Intercrystalline fracture is not excluded, particularly when the carbide forms intercrystalline films in low-carbon steels slowly cooled, and it is probable that the discrepancy between the notch-tensile and Izod tests on plates *D*1 and *D*2, annealed, *B* and *Z*, may be attributable to this cause. Further investigation of the detail of such fractures is proceeding.

I wish to thank H. M. Schnadt for the interesting communication on his work, with which I am already familiar.

H. M. Schnadt states in another form the theory already put forward by Ludwik, Joffé, Kuntze, *et alia*, that there is a flow strength and a fracture strength. The flow strength is more sensitive to temperature and rate of strain and conditions of test than the fracture strength. A reminder of this hypothesis has recently come from Orowan. The point at issue is this : Do any of the methods of test yet employed measure either of these "strengths" precisely ? There may be such a thing as intrinsic brittleness as defined by H. M. Schnadt, but how can it be evaluated and what is its value in terms of energy absorbed or stress to fracture ?

I am in general agreement with the rest of H. M. Schnadt's comments, particularly upon the importance of structure. This has already received some attention and is being further investigated at the present time.

Mr. **W. Barr** and Mr. **A. J. K. Honeyman** (Messrs. Colvilles Ltd., Glasgow), wrote : In reply to Mr. Burton, the weldability of mild steel is not adversely affected by increasing the manganese/carbon ratio, provided the tensile strength is not at the same time increased. The work done on medium-tensile manganese steels would indicate that for a given tensile strength the weldability is enhanced by a lowering of the carbon content and a corresponding increase in the manganese content.

With regard to heat-treatment, normalizing has the advantage of refining the grain-size, and for mild steels we have found it more effective in improving the impact values. However, it is true that with plates which are partially hardened in the as-rolled condition, tempering does considerably improve the impact value.

With regard to the possibility of still further increasing the manganese/carbon ratio, while our work has shown

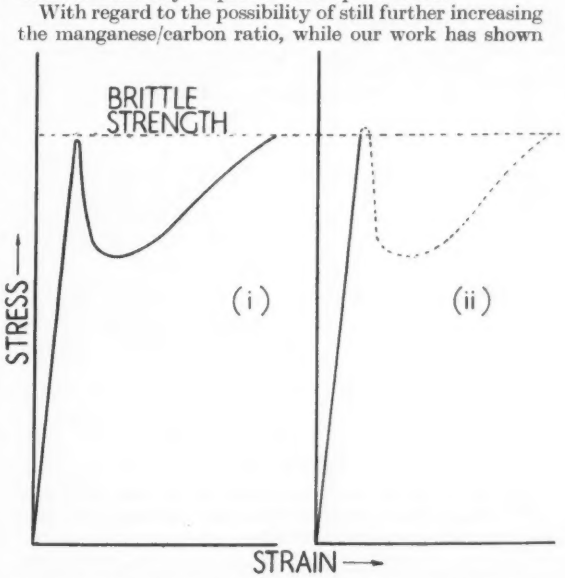


Fig. A—Effect of lowering the testing temperature on the type of fracture obtained

that this would lead to still further improvement in mechanical properties, the cost becomes prohibitive, particularly when the composition is such that low carbon ferromanganese is required.

In reply to Dr. Slater, Dr. Tipper has made some comment on the extent of the temperature transition range. However, we have noted that it is abrupt only in low carbon steels and it may, therefore, be related to the upper yield point. On this basis, if the brittle strength exceeds the upper yield point, considerable yielding will take place before fracture, as shown in Fig. A (i). When the temperature of testing is lowered till the upper yield point just exceeds the brittle strength, fracture will take place without deformation, Fig. A (ii). A wide transition range indicates a progressively decreasing plastic strain as the temperature is lowered.

It is difficult to understand Mr. Lewis' objection to the notched-bar impact test as a criterion of notch sensitivity. Since this property depends so much on the stress conditions, only a qualitative meaning can be attached to test results under any particularized stress conditions. However, there is every reason to believe that *for the same type of steel* in a similar condition, any chosen test of notch sensitivity would place the steels in the same order of merit. The discrepancy between steel *D*1 and 1229, and between steel *E*1 and 1278 is due to *D*1 and *E*1 being from open-hearth-steel plates and 1229 and 1278 being small-diameter bars rolled from high-frequency-steel casts. The suggestion that thinner plates of high-tensile steel with a high manganese/carbon ratio be substituted for thick plates of mild steel merits consideration, since at low temperatures a 35–40-ton steel with 0·23% of carbon and 1·5% of manganese gives better impact values than mild steel of 26–32 tons tensile with a manganese/carbon ratio of 3 or less. (*See* Fig. B.)*

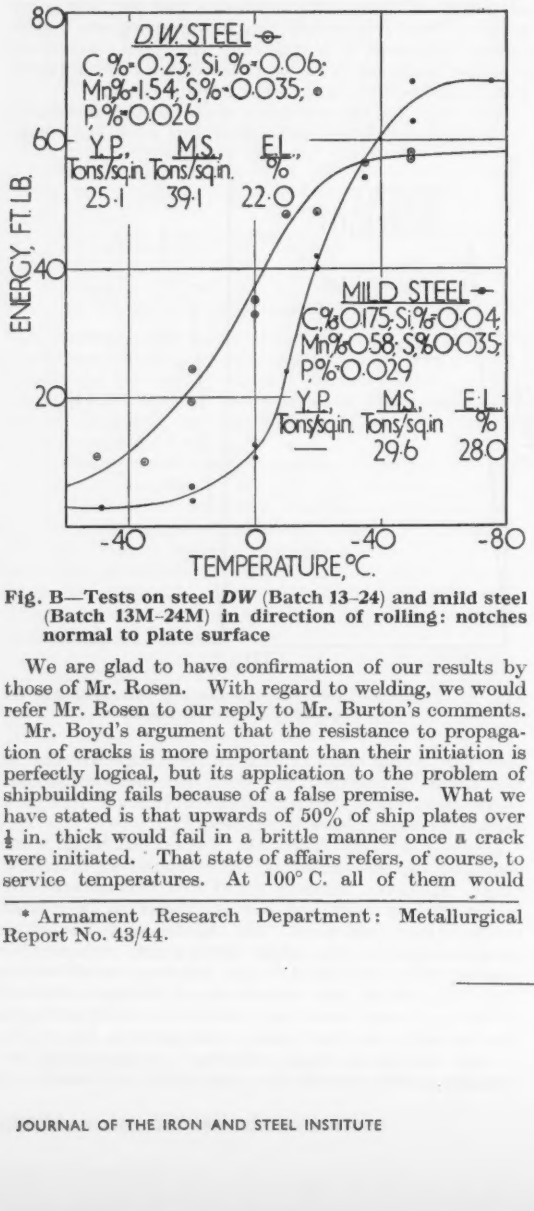


Fig. B—Tests on steel *DW* (Batch 13–24) and mild steel (Batch 13M–24M) in direction of rolling: notches normal to plate surface

We are glad to have confirmation of our results by those of Mr. Rosen. With regard to welding, we would refer Mr. Rosen to our reply to Mr. Burton's comments.

Mr. Boyd's argument that the resistance to propagation of cracks is more important than their initiation is perfectly logical, but its application to the problem of shipbuilding fails because of a false premise. What we have stated is that upwards of 50% of ship plates over ½ in. thick would fail in a brittle manner once a crack were initiated. That state of affairs refers, of course, to service temperatures. At 100° C. all of them would show 100% fibrous fracture and a very high impact value. The fact that failures occur infrequently is due to good design and workmanship, which combine to avoid excessive stresses and stress concentrations, and to steel of sufficiently low notch sensitivity to accommodate occasional excessive strains arising from stress concentrations which, fortunately, are themselves a rare occurrence. A standard testing temperature, as suggested by Mr. Boyd, if it were designed to reject "only a very small proportion of British shipbuilding steel," would require to be much higher than 20° C., and therefore would give very little indication of the behaviour of the steel at service temperatures.

The Cambridge Conference referred to by Dr. Main did not come to any definite conclusion as to the chief cause of the catastrophic failures in American ships. Since the Conference was discussing brittle fracture of steel, this factor was naturally very much emphasized, but there seems to be general agreement, both here and in U.S.A., that design and workmanship must bear the major share of responsibility. Plate *Z* was introduced as an example of really bad steel which sometimes finds its way into ship structure. As stated in the paper, the adjoining plates were not cracked or broken, and it is difficult to visualize structural factors in a riveted floor plate as being in any way responsible for the failure.

The interesting points discussed by Mr. McLean raise issues somewhat beyond the scope of the paper under discussion. However, we would express the opinion that alloy elements (apart from nickel) do not make quenched steel tough. One of the authors has shown elsewhere* that the notch toughness of quenched and tempered steel depends upon the efficiency of quenching. The maximum notch toughness, particularly at sub-zero temperatures, at any given U.T.S. obtained with tempering above 500° C., is achieved only when the steel has been fully quenched. Thus the contribution of alloying elements is due to their depth-hardening properties.

With regard to temper brittleness of manganese steels, the rates of cooling used by Greaves and Jones were exceptionally slow, and even mild steel, however high the manganese/carbon ratio, would show very inferior properties if cooled at an exceptionally slow rate.

H. M. Schnadt's first point is answered by pointing out that the effect of manganese/carbon ratio may be offset by an increase in tensile strength and that, therefore, comparison must be made between steels of the same tensile strength.

With regard to the relation between impact value and ductility, we would point out that in the reference quoted we are discussing the impact value when the fracture is 100% fibrous. In such cases it can be shown that the impact value is a function of the ductility of the steel.

While we agree with H. M. Schnadt that a notched-bar impact test is the most satisfactory way of determining the quality of the steel, this is not a practical proposition for shipbuilding steels and our recommendation of an increased manganese/carbon ratio would certainly have the effect of ensuring that, other things being equal, the impact value would be better.

* Armament Research Department: Metallurgical Report No. 43/44.

* A. J. K. Honeyman, *The Iron and Steel Institute*, 1946, *Special Report No. 36*, p. 253.

Discussion on—

SOME ASPECTS OF THE REFINING OF HIGH-PHOSPHORUS IRON*

by W. L. Kerlie

Mr. **W. L. Kerlie**, (Messrs. Stewarts and Lloyds, Ltd., Corby), introduced his paper.

Dr. **T. P. Colclough** (Iron and Steel Control, London), opening the discussion, said : I think you would like me to say first of all how much we welcome this maiden paper by Mr. Kerlie and how glad we are to find another of our young technical men contributing papers of this kind.

It is about twenty-five years ago that papers began to be written on the physical chemistry of steelmaking and the carbon and phosphorus reactions, and it is most gratifying to see the enormous progress that has been made in those twenty-five years.

I will not attempt to criticize in any way the technical aspects of Mr. Kerlie's paper—other members will be able to do that far better than I can—but I would say that we are at last beginning to see how the work which has been done on equilibrium constants and affinities can be translated into rates of reaction and give the real information that is required both in the open-hearth furnace and in the refining of iron.

I should like to stress the importance of the practical aspect of this exercise in the mathematical evaluation of the problem. This country is faced with a demand for higher and higher qualities of steel, for which we have only a limited supply of raw materials of the necessary purity. We are able to produce three grades of pig iron : one which has high phosphorus, in the neighbourhood of 1·6–2% ; that which has phosphorus in the neighbourhood of 0·6–0·7% ; and that which has phosphorus in the neighbourhood of 0·06% or less. We are desperately in need of a pig iron which has a range of phosphorus somewhere about 0·2–0·3%, in order to enable the necessary slag conditions to be established in the open-hearth furnace that will give the desired low phosphorus and sulphur contents of the steel. The practical aspect of the paper is valuable, in that the paper is an effort to show us the range in which we can hope to refine the higher-phosphorus pig irons which are available to us and make them suitable for the higher grades of steel manufacture.

Mr. **N. H. Bacon** (Messrs. Steel, Peech and Tozer, Sheffield) : I am particularly intrigued by this paper. I have not sufficient knowledge to criticize the author's physical chemistry, but, knowing him as I do, I feel quite confident that he has a very firm foundation for his calculations.

I am sure that many open-hearth managers must be interested in the paper, because it opens up a new approach to the preliminary treatment of the blast-furnace iron before its introduction into the open-hearth furnace.

There is no doubt that high-phosphoric iron—1·5–2%—can be, and is, successfully treated in large tilting furnaces which are producing both steel and fertilizer slag, but it is open to doubt whether the use of phosphoric iron is justified on economic grounds in the fixed furnace, cold charged, when any other material is available. Hematite, of course, is available, and personally I believe it is more economical to use hematite at its greater price, than to use phosphoric iron, but the paper opens up the prospect of getting a metal of 0·2% phosphorus content which would be a very suitable alternative to the metal we are at present using, with 1·5% of phosphorus.

I have made certain calculations to ascertain the benefits which would accrue to the fixed open-hearth furnace, and they are very striking. If we take 40% of 1·5% phosphoric iron and 40% of the refined iron given in the author's case I, which contains 2·4% of carbon and 0·25% of phosphorus, we get the following figures :

Charge (87 tons)	40% Phosphoric Iron	40% Refined Iron
Lime consumption	7·0 tons	2·35 tons
Oxide consumption	5·3 tons	Nil
Slag weight ...	17·2 tons	6·0 tons
Output, tons/per gross hr. ...	6·4	7·8 (21·8% increase)
Ingot yield from chargings ...	90·0%	92·47%

Some very substantial economic benefits should result. Assuming that the irons were the same price, the savings in terms of ingot cost should be as follows :

	Reduction in Ingot Cost	Based on 1947 prices, per ton approx.
2 hr. less furnace time ...	2·6%	5*s.* 2*d.*
2·47% higher yield	2·4%	4*s.* 6*d.*
Reduced consumption of lime, fluorspar, and dolomite	1·8%	3*s.* 5*d.*
Total	6·8%	13*s.* 1*d.*

Converting that back to the iron, it comes to this, that an approximately 26% higher price could be paid for this refined iron than for ordinary basic iron, or about 30*s.*/ton at current prices, and there would still be left, of course, the very substantial gain of 21·8% increase in the rate of output. We should also have the benefit of the fertilizer slag. The phosphorus which is charged into the fixed furnace is lost altogether as a fertilizer, and that is a loss which we can ill afford today.

There is one fly in the ointment. Owing to the very low carbon, silicon, phosphorus, and manganese contents of the refined iron, at least 40% would be required in a cold-charged furnace to get a satisfactory carbon melt. Therefore at a time when ample scrap was available we should require to add carburizing material with the cold metal charge, which would reduce the speed of melting and so offset to some extent the advantages of the refined iron. I should like to ask the author whether it would be possible to do some recarburizing of the iron in the ladle, or, alternatively, whether it would be possible mechanically to mix carbonaceous material with the metal during the process of casting the pig in the casting machine. If the carbon could be increased by that means, the refined iron would be equally beneficial, whatever percentage of scrap was available on the market. Recently we have had 70% or 75% of scrap available. We are feeling the pinch now. Usually the average amount of scrap available for the fixed furnace is nearer 60% than 70%.

One objection which might be raised is with regard to the slag volume. I mentioned that the slag weight in the case of the phosphoric iron was 17·2 tons and in the case of the refined iron 6 tons ; when I talk to open-hearth managers they often say : " You cannot get the sulphur out with such a low slag volume," but in this case it would be adequate, because the author's refined

* *Journal of The Iron and Steel Institute*, 1947, vol. 157, Oct., pp. 173–182.

iron contains only 0·03% of sulphur, and such a low sulphur content would be an essential feature of the process in order to work with only 6 tons of slag. A calculation shows that in the case of the phosphoric iron the total amount of the sulphur in the metal and the slag would be 177 lb., whilst in the refined iron it would be 102 lb. The tapping-slag analyses would be approximately as the following :

Fe, %	SiO_2, %	CaO, %	P_2O_5, %	MnO, %	MgO, %	S, %
40% Phosphoric Iron						
12·0	11·8	50	7·3	3·0	5·0	0·28
40% Refined Iron						
12·0	15·0	50	4·0	3·4	5·0	0·27

It has long been proved advantageous to give the blast-furnace metal some preliminary treatment before its introduction into the open-hearth furnace. The mixer has been developed into a semi-refining furnace, where the silicon is substantially reduced, say, from 1·0% to 0·2%, and there is usually about 10% to 25% reduction of sulphur. The phosphorus, of course, remains as it was, and the slag from the mixer is of no particular value. If the mixer could be further improved, on the lines suggested by the author, its value as an aid to increased steel production would be very greatly enhanced.

Mr. **F. L. Robertson** (Messrs. John Summers and Sons, Ltd., Shotton, near Chester) : The author has grasped what has been one of the outstanding nettles in the steel trade for many years. How does it come about that the operation of oxidizing phosphorus, which is an exothermic reaction, is in practice carried out at the same and often at a higher temperature than the oxidation of the bulk of the carbon, which is an endothermic reaction ? How is it that the Hoesch process or the fundamental principles lying behind the Hoesch process have been absolutely neglected in British steelmaking, especially during the war ? At one time it would have paid us to carry out that process. The Hoesch process does work. The only thing is to start regulating the silicon. I have got tappings down to 1·5% of carbon and 24% of P_2O_5.

The answer lies in the fact that the quantitative chemistry of phosphorus elimination has really only been put on a firm foundation and a well-advertised foundation in the last fifteen years, and the important matter which the author has brought forward, namely, the velocity of carbon reaction or carbon elimination at low temperatures, is hardly ever discussed amongst steelmakers. Some two or three years ago the Institute of British Foundrymen's Basic Cupola Lining Committee, under the chairmanship of Mr. Bolton, discussed this point which the author has raised. We wanted to dephosphorize in the ladle and then decarbonize, as the Stanton Gate foundry did during the war, in a surface-blown converter. Last year, at a joint meeting of the Institute of British Foundrymen and The Iron and Steel Institute, this matter came up again, but it could not be dealt with for want of the arithmetic that the author has now supplied, and I should like to record what an important epoch this paper is likely to inaugurate for us.

I should like to ask the author whether, in following up this very splendid approach to the problem generally, he is not being a little too bold in jumping straight to a 150-ton furnace ? I do not mean to say that we could not use a 150-ton furnace ultimately, but I think he is going to it too quickly. If he has not got the apparatus to do it himself, would not he induce some institution which has the apparatus to agitate iron mechanically at a definite temperature, which I would suggest should be between 1300° and 1400° C. (I do not see why it should not work at 1300° C.), with an already molten slag ? I would suggest that the experiment should be done on what I call a workshop scale, say, a 5-cwt. scale. I would further suggest that the choice of a slag would lie between what the author has proposed, possibly enriched with soda to lower its melting point, and a pure calcium ferrite slag of about 74% iron oxide, which I think melts at about 1250° C.

When this matter was under discussion by the Basic Cupola Lining Committee, Mr. Evans, of Imperial Chemical Industries, Ltd., carried out some experiments, which he was good enough to show me in the course of operation, in which he charged sodium carbonate and scale on to molten iron. These experiments actually dephosphorized. The slag that he got on the top of his crucible contained 26% of P_2O_5. The experiments are described in their report.*

I ask again whether the author would not test his calculations on this small scale. The interest that he would arouse amongst steelmakers would be immense, and I am sure that it would kindle our imaginations as much as, if not even more than, the very brilliant arithmetical approach that he has just given us.

I should like to endorse what Mr. Bacon has said. He has approached this matter from the Siemens point of view, and there are tremendous figures of economy in that approach, with which I am very sympathetic. I think he can dismiss the sulphur. There is no reason why the big blast-furnace people should not do what the small foundrymen showed was absolutely practicable, namely, desulphurize. Sooner or later we shall have to compete with America. There will be a show-down some day. America can produce slag weights of 5%, or at any rate under 10%, whereas we run up to 30%, and certainly 25% is quite common for low-sulphur steels.

Dr. **J. H. Whiteley** (Consett Iron Company, Ltd., Consett, Co. Durham) : Mr. Bacon showed us a saving of 13*s.* 1*d.* per ton by the use of iron refined in the way outlined in the paper, and I should like to ask him whether that saving includes the cost entailed in running a second furnace.

Mr. **N. H. Bacon** (Messrs. Steel, Peech and Tozer, Sheffield) : I thought I had made it clear that, if we take two irons, one with 1·5% of phosphorus and the other with 0·25% of phosphorus, using 40% in each case, in an open-hearth cold-charged fixed furnace, and charge the two irons to the furnace at the same price, the resulting ingot cost would show a difference of approximately 13*s.* 0*d.* per ton. I further said that if that 13*s.* 0*d.* is taken back as a charge on the iron it will allow an increased cost of the refined iron of about 30*s.*, and that, in charging two furnaces, one with phosphoric iron at the normal price and the other with 40% refined iron at an increased cost of 30*s.*, the resulting ingot costs would be even, but there would remain a very great gain, *viz.*, the 20% increase in output rate.

Dr. **F. D. Richardson** (British Iron and Steel Research Association, London) : I was very interested in this paper, particularly because it made me think hard on the subject of reaction rates. I should like to underline the author's warning on p. 175. It is not possible to link up the free-energy change (the affinity) with the rate of change in the reacting system as clearly as the author suggests without introducing a clear picture of the factors governing the rates of the particular process. Such a picture would have to be very different from that for " normal " reactions, where the rate of interaction

* *Institute of British Foundrymen, Third Sub-Committee Report No.* T.S. 10, 1947, February.

of the reacting molecules is the limiting factor. It seems to me that the rate-determining processes would have to be convection and diffusion to give a relationship of the type suggested.

In Fig. 3 of the paper, the author has plotted the rate of carbon removal for the two systems, which he refers to as (*a*) and (*b*). It is, of course, immediately obvious that if we have a system in equilibrium and we heat it up, taking it to some temperature at which it is not in equilibrium, there will be a reaction taking it to the new equilibrium state. The more remote the temperature to which we go, the further the system will be removed from equilibrium, and the greater the velocity at which the reaction will initially proceed.

In such a process, however, we would be changing two things at once—the extent of the disequilibrium and the temperature. By increasing the temperature we are of course increasing what is normally understood as the true reaction rate of the chemical process under consideration. The apparent correlation shown in Fig. 2 is therefore to be expected, whether or not there is any significant relation between the free-energy change and the rate.

In considering how much free-energy changes or equilibrium conditions do govern velocities in these particular high-temperature systems, it would be very interesting to see the effect of putting a system out of equilibrium by reducing the temperature. We could then see whether the velocity increases in as nice a manner as shown in Fig. 3. It may be that the author has in fact some figures to give us in that connection; if he has, I should be very interested to hear of them, because I think they might lead us to a real understanding of the possibility of the link-up that the author suggests.

I have a small criticism to make on Fig. 3 of the paper, with regard to the dotted lines with which the plotted curves are joined to zero. The author suggests that the negative values of v will not obtain in actual practice, because as v tends towards zero the pressure of the carbon monoxide will decrease. I do not think that it will decrease; I think it will remain much the same. But if it did decrease it would not reduce the value of the free-energy change; it would in fact increase it. Therefore any dotted lines which are introduced, in order to account for the supposed reduction of the carbon monoxide pressure, should move the curves even further away from zero. I may be wrong, but I think the true explanation of the offset of these two curves from zero is that for the free-energy change the author has used Chipman and Samarin's equilibrium data and for the velocities he has used Schenck's velocity data. As can be seen in Fig. 2 the two sets do not match up except at the very low carbon concentrations. It is obvious, therefore, that if what I say is correct the rates curves should pass through the origin in Fig. 3 over the range where Schenck's and Chipman's results agree, but they would obviously not do so at the higher carbon concentrations. This is, in fact, the case, since the curve for the low-carbon concentrations comes fairly close, whilst that for the high-carbon concentrations is the one particularly displaced from the zero.

There is one further point that I should like to make; that is, with regard to the real meaning to be attached to an intersection of the type shown in Fig. 5, where the affinity or free-energy curve for the oxidation of carbon intersects that for the phosphorus reaction.

To my mind, the only firm meaning that can be attached to the intersection is that the affinities for the two reactions are the same at the temperature in question; the two reactions have the same free-energy change. If we subtract one equation from the other we get zero free-energy change, and an equilibrium condition in which the FeO cancels out. This intersection cannot tell us anything about the relative rates of the two reactions, when we introduce the FeO, without a clear picture of the mechanisms of the reactions. This involves a clear picture of why we really are linking the free-energy change to the rate of change of the system. With a picture of this type, however, it seems to me that we should be running out phosphorus at a percentage rate of about twice that at which we should be running out the carbon. It may be, of course, that I am trying to read the author's note on this intersection a little too deeply, but I should not be prepared to say that the carbon oxidation will occur preferentially at temperatures immediately beyond that point.

Mr. **T. F. Pearson** (Consett Iron Company, Ltd., Consett, Co. Durham): I wish to express my appreciation of Mr. Kerlie's paper because the author has brought forward a matter which has occupied my mind for a long period. The possibility of effecting an intermediate purification of high-phosphorus iron is extremely important and also very fascinating.

I doubt, however, whether the author's slags would work in practice. I suggest this because of some work done a year or two ago in Scotland on basic open-hearth slags, the results of which emphasize a point raised by various speakers, namely, the difference between true equilibrium conditions and those often present in practice. The author suggests slags which, if present on a flat bath such as that of a mixer, would not hold phosphorus in a stable condition and any disturbance of which would cause serious reversion. While the lower temperature is favourable I doubt whether it would compensate sufficiently, for other reasons.

The work to which I refer was an attempt to discover whether it was possible to ascertain a measure of slag composition in the open-hearth furnace sufficiently rapidly to allow quick corrections to be made. I do not think that the chemical determinations of SiO_2, P_2O_5, and CaO are sufficiently rapid—and they are certainly clumsy—so we tried to introduce a physical measurement.

Some years ago work was done in America on the measurement of the *p*H value of slag suspensions and it was thought that this test might offer attractive possibilities. Accordingly a large number of tapping slags were carefully analysed and the *p*H values of their suspensions (100-mesh B.S. sieve) determined in conditions very different from those of the American work. We found that it was necessary to buffer the suspensions down to *p*H 4–6 in order to come on to the straight-line portion of the glass-electrode calibration curve, and it

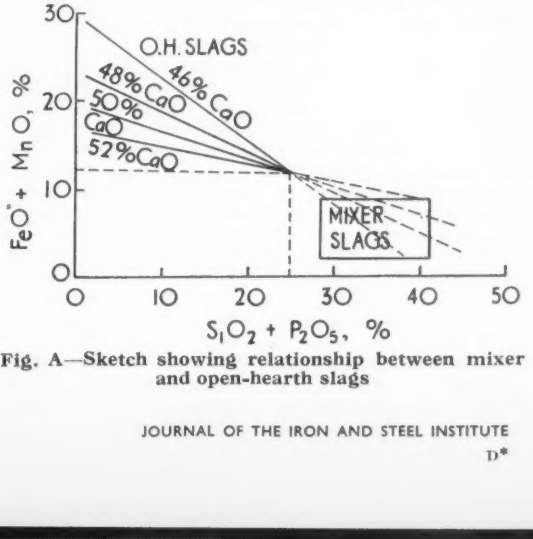


Fig. A—Sketch showing relationship between mixer and open-hearth slags

was only by this means that we could get reproducible and hence comparable figures for different slags.

For the purpose of classification of results, slags of constant lime (or CaO + MgO) content were first recorded by plotting their FeO + MnO contents against their $SiO_2 + P_2O_5$ contents. The total of all these constituents accounted for the major portion of the slag and was very nearly constant for normal slags.

It was then found that if the best lines for these constant CaO + MgO plots were calculated, they converged to a common point situated at 25% $SiO_2 + P_2O_5$ and 12% FeO + MnO (*see* Fig. A). It was also found that the *p*H values varied in the main with the CaO + MgO contents and it was visualized that a slag composition with respect to $SiO_2 + P_2O_5$ and CaO + MgO could then be located if a very rapid determination of the "FeO" (total Fe) + MnO (say, by Spekker) were made, together with a *p*H measurement—a matter of minutes. This would certainly be much quicker than the laborious methods used at present.

Referring to Fig. A we find that if these constant "lime" lines are extrapolated we come down to mixer slag compositions where the "total acid" content is now almost wholly SiO_2 instead of $SiO_2 + P_2O_5$ and the CaO content is being replaced by increased MgO, *i.e.*, slags which do not hold phosphorus.

It is suggested, therefore, that for normal flat-bath conditions to obtain dephosphorization the "total acid" content must be below 25% and the FeO + MnO above 14% (in contrast to the author's slags). We know that all open-hearth slags fulfil this composition requirement where phosphorus stability in the slag is achieved, *i.e.*, where there is no rephosphorization on tapping; and it appears doubtful to me whether the temperature could compensate, since some agitation is necessary, and this could only be brought about by a "boil" which is difficult to achieve at mixer-temperature levels and which, if achieved, would result in a rapidly increased bath temperature, so defeating its own object.

Reverting to the author's point, is it not preferable, therefore, in a mixer to desiliconize and then remove the SiO_2? This would certainly give increased opportunity for any slag to hold P_2O_5, and new and more suitable mixer slags are not beyond the bounds of possibility. This problem could be investigated ideally in a two-mixer shop, but would not be so easy with one furnace because of the frequency of disturbance caused by off-taking metal for the furnaces. The field is, however, fruitful and we owe a debt of gratitude to the author for bringing forward his paper.

AUTHOR'S REPLY.

Mr. **W. L. Kerlie** replied: I should like to thank those who have contributed to the discussion for the constructive remarks which they have made.

With regard to the points raised by Mr. Bacon, it would, I think, have been very nice to have some cost figures showing the advantage, if any, that would accrue by using a refining process such as is described in the paper. Mr. Bacon mentioned one snag, namely, that the iron produced by a refining operation such as I have described would be low in carbon, silicon, and phosphorus, and that in all probability additions would be required. Mr. Bacon pointed out that the question of the carbon was the most important one. Obviously, if refining is to be carried out, the higher the carbon in the iron to start with the better. It may be possible to add some carbon in the form of coke breeze to the blast-furnace iron as it goes into the ladle. It may be possible even to add more carbon to the metal before carrying out the refining process. There are various methods which might be evolved, and there is also a third possibility which perhaps would answer the question about sulphur. If we had a direct process carried out in one furnace and we did the necessary refining and removed the slag, I do not see why it should not be possible to build up a final slag of a reducing nature. The carbon could be fed as hard as was desired, and the sulphur could be taken out in the reducing slag. There would probably be one snag, namely, the difficulty of getting the necessary temperature for the purpose, but in this case it should be possible to raise the temperature without detriment to the phosphorus content and to transfer the iron in a very good and hot condition to a hot-metal furnace.

Mr. Robertson asked how the phosphorus reaction, which is an exothermic reaction, could be carried out at the same temperature as the carbon reaction, which is an endothermic reaction. I would point out that, according to Chipman and Samarin's work, the indications are that at extreme temperatures the FeO-plus-carbon reaction, or the reaction of FeO in solution plus carbon in solution, is exothermic. I calculated it out some time ago, based on Chipman and Samarin's work, and found it to be something of the order of 11,000 calories at 1600° C.

Another point raised by Mr. Robertson was that the use of a 150-ton furnace in following-up this work might be rather bold, but there is one great advantage in using a big furnace and carrying out an experiment on a big scale, that is, the errors, if any, may be small in comparison. I do not think that, if the furnace were available, the experiment would be an expensive one. If the required object could not be achieved, one could always guarantee that some dephosphorization would take place, and the metal would not be lost; it could be used to carry on the practice as before.

There remains the question of choosing the furnace in the proper area for experimental work. I agree with Mr. Robertson that experiments on the influence of soda as a dephosphorizing agent might be well worth while, and a small furnace of a capacity of 5 cwt. would be ideal for such an experiment.

I was very interested to hear from Mr. Robertson about the experiments carried out by Mr. Evans, of Imperial Chemical Industries, Ltd., in which something like 26% of P_2O_5 had been obtained in the slag.

With regard to the diagram which was put on the blackboard by Mr. Pearson, it occurred to me, when Mr. Pearson was explaining the fan-shaped lines of mixer slags, that the steelmaking temperatures would be maintained, so the mixer slags described by Mr. Pearson would be operating at a temperature of 1600° C., and the dephosphorization would not be anything like that obtained at much lower temperatures.

Mr. Richardson suggests that, in linking up the rate of change in the reacting system with the affinity, it is necessary to stipulate the factors governing the rates of the particular process. In the case of the phosphorus reaction such factors as diffusion and degree of contact are no doubt of importance and will be influenced by the turbulence caused by the FeO-plus-carbon reaction. It should be remembered that by adjusting the slag composition and temperature, the rate of phosphorus removal in the open hearth can be varied relative to the rate of carbon removal, and *vice versa*. For the carbon reaction, however, it would appear that the chemical change is slower than the rate of diffusion of FeO from slag to metal or the rate of bubble formation for rates of carbon removal above 0·0005%/min., and the rate of carbon removal is the determining factor for the entire reaction involving diffusion, bubble formation,

etc. Evidence for this lies in the fact that the oxygen content of the bath can be calculated from the rate of carbon removal and good agreement has been obtained with oxygen determinations of bomb samples.

The correlation between the affinity of the carbon reaction and the rate of carbon removal may be explained thus :

The rate is given by the equation :

$$v = k_1 [C] [FeO] - k_2 p_{CO} \quad \ldots\ldots\ldots (a)$$

the equilibrium constant by :

$$\log K = \frac{2400}{T} + 0{\cdot}675 \quad \ldots\ldots\ldots (b),$$

and since $-\Delta G = RT \ln K - RT \ln X$,

$$-\Delta G = 10{,}980 + 3{\cdot}09T - 4{\cdot}573T \log \frac{p_{CO}}{[C] [FeO]}$$

From equation (a) and assuming p_{CO} constant at 1 atm. :

$$-\Delta G = 10{,}980 + 3{\cdot}09T + 4{\cdot}573T \log \frac{v + k_2}{k_1}$$

Thus the lines indicated in Fig. 3 are exponentials.

With regard to the criticism of the offset of the two curves from zero, it is now obvious that on increasing the temperature the affinity will increase both by virtue of the temperature rise and by the consequent increase in reaction rate (saturation value of [FeO] increasing).

With regard to the explanation of the dotted lines in Fig. 3, clarity has been sacrificed for brevity on a point of illustration not germane to the main issue. I hasten to explain further that as v and $-\Delta G$ approach zero, a stage will be reached when the available energy change in the reaction will be insufficient to promote the formation of bubbles of CO. I estimate that this will occur when the rate of the reaction is less than 0·0005% of carbon per min. I should also explain that the data I have used in the construction of Fig. 1 and developed in Fig. 2 (curve 1) are based on $p_{CO} = 1{\cdot}1$ atm., the average pressure within the bath, whereas the laboratory data of Chipman and Samarin (curve 2) are based on $p_{CO} = 1{\cdot}0$ atm. If the pressure correction were applied the two curves shown in Fig. 2 would tend towards coincidence at the higher carbon contents.

Mr. Pearson has raised a very interesting point with regard to the ability of open-hearth slags to hold phosphorus. The slags he describes obviously refer to steel finishing at approximately 0·04% of phosphorus, and I should like to point out that dephosphorization depends also on the amount of phosphorus present in the metal. I would submit that his results tend to confirm the points brought out in the paper, particularly when the temperature is taken into consideration. The curves he has drawn would move to the right with increasing phosphorus and decreasing temperature.

Discussion on the Paper—
A PHOTO-ELECTRIC ROOF PYROMETER FOR OPEN-HEARTH FURNACES*
by T. Land

Mr. **J. A. Hall** (National Physical Laboratory, Teddington, Middlesex), opening the discussion, said : The author has presented his paper in two parts, and I think that my contribution to the discussion will similarly divide itself. The author, speaking of the use of barrier-layer photo-cells for pyrometry in general, referred to some work which he did, and to which I contributed a certain amount, about four years ago. The part of that work on which I concentrated—because it seemed to me, when I started to play with these cells, that it was the factor which was likely to swamp almost anything else as a source of error—was the problem of drift or fatigue.

The conclusion to which the author and I between us came at that time was that if one was prepared to select about 50% of a batch one would get cells which were good enough for temperature measurement to a tolerably high degree of precision. Recently, however, we at the National Physical Laboratory have carried out a test on a batch of 50 photo-cells of the type which the author is using in his pyrometer, and I thought that it would be of some interest to show how they compare for drift with the cells which he and I tested in 1943.

I may say that in correlating the author's values with mine in the early work I have increased the values of drift which he found, because his observations were taken after the cell had been in darkness for 30 min., whereas mine were taken after the cells had been in darkness for upwards of 24 hr., and the latter condition applied to the recent examination of cells at the Laboratory.

Figure A refers, therefore, to the drift after prolonged exposure to darkness. It shows the frequency of occurrence of any particular magnitude of drift expressed as the percentage drop between the first and tenth minute of exposure. The dotted curves refer to the cells

* *Journal of The Iron and Steel Institute*, 1947, vol. 155, Apr., pp. 568–576.

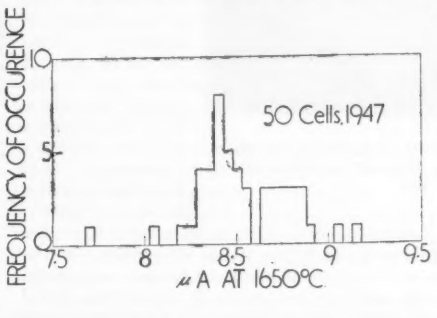


Fig. A—Drifts of two batches of photo-cells

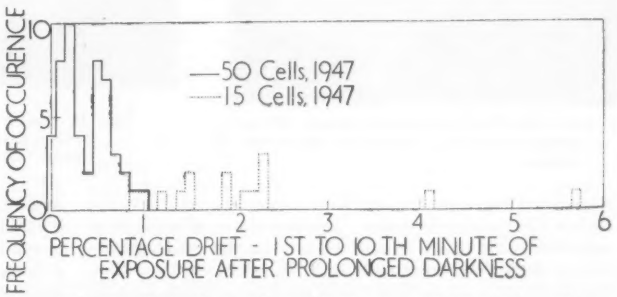


Fig. B—Variations of sensitivity among 50 photo-cells

Fig. C—Roof of gas-fired furnace during charging viewed in direction of flame

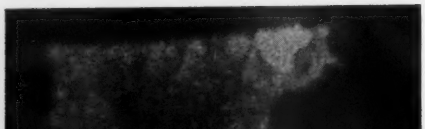


Fig. D—As Fig. C, but with gas off during reversal

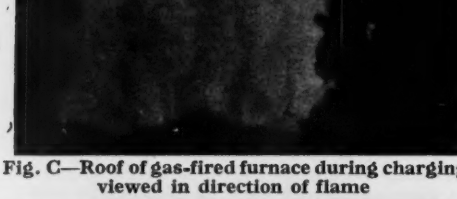


Fig. F—Roof of oil-fired furnace during charging, viewed in direction of flame (*cf.* Fig. C)

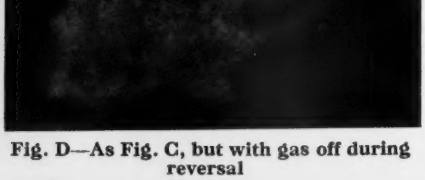


Fig. E—As Fig. C, but viewed in opposite direction to the flame

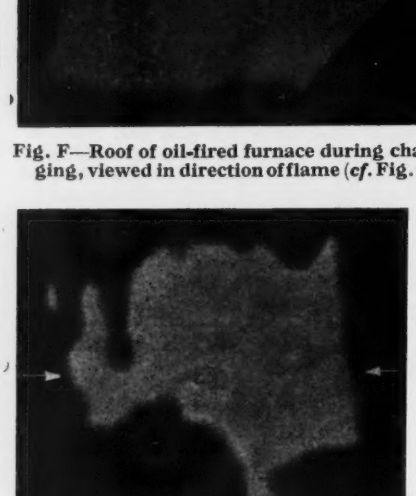


Fig. G—Roof of gas-fired furnace, 25 min. before tapping, viewed in direction of flame

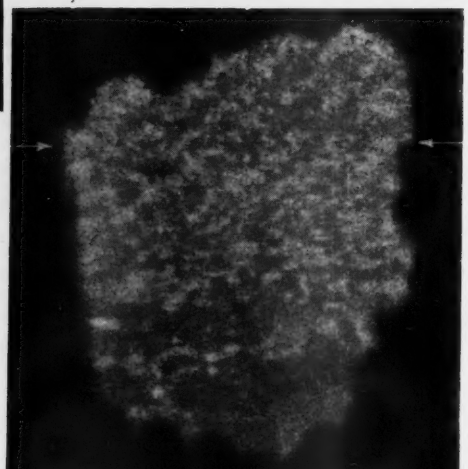


Fig. H—Roof of oil-fired furnace, 65 min. before tapping, viewed in direction of flame (*cf.* Fig. G)

tested in 1943, and the full line to the 50 cells analysed within the last few months. I do not know whether it is significant, but it will be noticed that on the left there are two groups, one round about 0·2% drift and another round about 0·6%. One could perhaps imagine that in the earlier work there were groups at about 1·3% and a little over 2%, though that is perhaps a little far-fetched. The diagram does show, however, that a quite remarkable improvement has been made in these cells over the last four years ; and if the conclusion was that the accuracy obtainable was comparable with, or even slightly superior to, that of the normal commercial disappearing-filament pyrometer of English manufacture at that time, I think that we have little cause to worry on the score of drift nowadays.

Figure B shows how the 50 recent cells differ among themselves in sensitivity. The graph shows micro-amperes developed in an optical system similar to that used by the author. The total range is about 7·7-9·3μA. at 1650° C. Clearly we cannot accept all cells as having the same calibration, but the differences between cells are such that they can readily be compensated in any measuring circuit used.

The second part of the paper is of a more theoretical character. I do not think that I have any comments to make on the validity of the author's reasoning, but from the comparatively small experience which I have had of looking at open-hearth furnace roofs I could not quite believe that everything in the garden was as lovely as his calculations suggested. I hope that he will correct me if I am wrong, but I have a feeling that perhaps he was a little suspicious himself.

I was in Sheffield about a fortnight ago, and it occurred to me that it would not be a bad idea to take some photographs of the roofs of open-hearth furnaces, both oil- and gas-fired, because it seemed to me on looking at them that there was a profound difference between the appearance of the two types. While I was not in a position, for various reasons, to take photographs which I could use for accurate measurement purposes, I could at any rate get a rough approximation to the brightness temperature of the roof, and, somewhat more accurately, to the variation in brightness over an area of the roof. These photographs were all taken on the basic open-hearth furnaces at Templeborough, with the very kind permission and co-operation of the United Steel Companies, Ltd., and their staff.

The photographs of the first group were taken during the charging period, and Fig. C shows a gas-fired furnace in which the roof was 17 weeks old. The furnace started charging at 9.30 and finished charging at 2.20, and this photograph was taken at about 12.10. The furnace at that time was being charged with mixed heavy scrap. I have done a very rough analysis on the densities of the negatives ; I just traversed once across each negative from right to left at the level marked by the arrows, so that in Fig. C I have taken in some of the rather dark areas shown, which is perhaps not quite fair. My temperature values may easily be 50° C. out in absolute value, but the accuracy on a small difference will be better, and in this instance I found fluctuations in brightness over a range corresponding to 1680–1710° C. The photograph was taken in the same direction as the flow of gas through the furnace, *i.e.*, with the flame.

Figure D was taken during reversal, when the gas was off, or nearly off. Here again traversing from right to left the brightness temperature is now very much lower, and runs from about 1530° C. to 1560° C., again an amplitude of about 30° C. The light patch in the top right-hand corner is a photographic defect. Almost immediately afterwards, when the gas had come on in the other direction, I took the next photograph, shown in Fig. E, looking against the flame. It is very much brighter at the bottom, and that is probably a trace of flame or reflection of flame from the verb at the other end of the furnace. A traverse showed the temperature running from 1580° C. to 1630° C.; a variation of 50° C.

Those photographs are all on a gas-fired furnace ; Fig. F, comparable with the first of them, is a corresponding shot on an oil-fired furnace. Here the roof is only two weeks old. These photographs were taken with a reflex camera, and I noticed on looking at the field of view that there was flame coming and going all the time, and it was a matter of chance whether I missed it or not. Here the roof is only visible in the upper part of the photograph, but it can be seen by eye that there is a considerably more marked variability in the brightness than with the gas-fired furnace. I took a traverse right at the top, and the temperatures ran from 1530° C. to 1590° C., so that the amplitude of variation was up to 60° C. That, it is true, was not quite under conditions comparable to those of Fig. C, because it was taken right at the end of charging ; in fact the last batch of the charge had just gone in, and that was pig iron, so that there would be pig iron floating in the bath which would be very uneven in surface brightness.

Now let us consider a companion set of photographs taken at a later stage, *i.e.*, during refining. Figure G is of a gas-fired furnace, looking again in the direction of the flame. The roof is 24 weeks old. The charge was a low-carbon steel, and the photograph was taken at the going-on stage, just 25 min. before tapping, so that there would be full heat in the furnace and the bath would be quiet. A traverse shows a variation of only about 10° C., at about 1680° C.

Finally, to compare with that, Fig. H shows a corresponding shot of the roof of an oil-fired furnace. This roof was 32 weeks old, and it was the last day of its life. This photograph was taken 65 min. before tapping. The charge was a high-carbon steel, finishing at 0·60–0·64% of carbon, so that there would be a good boil on the bath when this shot was taken. The dark part at the top is probably the verb at the near end of the furnace, but this gives a good view of the roof, and if a traverse is taken across at about the middle of the roof values of 1580–1630° C. are obtained ; an amplitude of variation of about 50° C.

That seems to me to bear out the idea that there is a bigger variation in apparent brightness from place to place in the roof with an oil-fired furnace than with a gas-fired furnace. Considering Figs. C and F, which were taken during charging, there was a 30° C. variation with gas and a 60° C. variation with oil, while during refining the variation was only 10° C. with gas and 50° C. with oil (Figs. G and H).

This rather suggests that, while a pyrometer such as the author's may give a good, steady reading, and one which will be quite satisfactory for operating the furnace, it is still by no means certain what relation the readings of that pyrometer will bear to the true temperature of the roof.

It will be realized from what I have said that these photographs were taken along the length of the furnace. They were taken through a hole alongside the gas port, while the general practice is for a pyrometer to sight from above the tap-hole to the centre of the roof, and that may produce appreciably different results. Clearly, however, in view of the need for careful choice of the sighting place and some consideration of the fact that the roof certainly does not exhibit a uniform brightness (even at such a late stage as that at which the last photographs were taken), there is a good deal of work still to be done.

Mr. **F. L. Robertson** (Messrs. John Summers & Sons, Ltd., Shotton, near Chester) : To start with, I should like to say that the roof-temperature measuring apparatus is by far the most important of any instrument on a melting furnace. The ease with which a furnace roof can be melted has forced managerial and engineering staffs to adopt many practices which undoubtedly have militated against the good of the trade, and one of them has been to keep the layman with bright ideas from messing about in the shop.

Very few men apart from melters themselves realize what an emotionally disturbing thing it is to the manager and to his melters in a shop to melt a roof. Now that we have some measure of roof temperature we can afford to play with things like port sizes and different fuels and the many other ideas that occur to the ordinary active mind, without raising the absolutely dumb opposition of the melting staff, which is also usually mingled with a great deal of fear on account of the roof.

The firm with which I am connected has pioneered in this country the radiation tube pyrometer for roof-temperature work. It will be nine years next January since we started to run all the furnaces in one shop to strict roof-temperature rules, and shortly afterwards the other two shops followed suit and did the same. We have considered the radiation tube a wonderful blessing, and a great many of our melters would have to learn melting all over again if they had not roof-temperature measurement ; but every now and again we think that we could do better. It is very interesting to find that we

can in one shop, with no managerial difference to account for it, run at the same time gas-fired furnaces at 1680° C., while for oil-fired furnaces we come down to 1640° C. It is not clear why, but the author has dealt with a possible explanation or explanations. I am almost frightened to refer to them, because of my ignorance of his technology, but he gives a table for the interference of dust and dirt and different gases, and I think that on that point his pyrometer may be a very great help to us.

The greatest, and in fact the only, difficulty which we had in getting radiation tubes which had not been made for roof-temperature work to work was to invent a suitable housing to hold the tube. Like the author, we use compressed air to keep a pressure in front of the instrument to prevent dirt and dust from the furnace coming in. But engineers are (I do not know why) quite unable to deliver compressed air to a melting shop without oil, and this has been an immense trouble to us. I am greatly struck, therefore, by the design given in the paper, showing how the compressed air impinges on the protecting tube in front of his instrument. I think that that is a brilliant idea.

I notice that the author suggests running his pyrometer without frequent calibration with a disappearing filament on the roof. We have from the beginning always done that, and I suppose that having once started we went on with it. We do it as an insurance ; but a false impression has got about that a radiation tube must be calibrated every hour. The calibration does change, but it changes at a rate such that the instrument people in a works can keep pace with it. The deposit of oil and dirt on the mica sheath, and the danger of getting blocks of slag or brick in the line of vision, and so on, are really why we keep to it. It is a matter for every melting-shop manager to decide whether the insurance is worth while or not.

I am in thorough agreement with the author, and with Mr. Thring and Dr. Chesters in their paper a year ago, that the temperature at which you run the roof is a terrific factor in the speed. I should like to know whether we have to keep low with the radiation tube for safety's sake because of its variation, and whether with the author's pyrometer we can be bold and work straight-away at 1670° C. I want to say 1680° C., but I will give away 10°.

I am most grateful, as I am sure all melting-shop managers are, and speak with real emotion when I say it, to all engineers, inventors, and scientists, like the author and Mr. Hall, who stretch out their hands to help us in the awful responsibility of running many furnaces—not one—within 20° C. of their melting point. It is a heart-searching matter !

If I may comment on a remark of Mr. Hall's, the place at which to measure the roof temperature is a matter which needs a great deal of research. We started at Shelton with one place, in the middle. In our other works we took two places, and when oil came in we liked to have three, one at each end and one in the middle, and the two end pyrometers read differently. I am told that the port can be designed so that either the outgoing end or the incoming end of the roof can be made hotter. There is therefore room for a good deal of research, and I think that Mr. Hall's approach to this matter is very pertinent indeed.

Dr. **J. H. Chesters** (The United Steel Companies, Ltd., Stocksbridge, near Sheffield) : Having listened to Mr. Robertson, I share all his emotions. We are, as it happens, staking our all on this particular development, in that we hope in the near future to go in for automatic control on at least one furnace, and probably on two. The whole scheme is based on the use of a roof pyrometer as the master controller. It will control the oil flow, which in turn will control the air flow, and, since the oil will be linked also to the atomizing steam, the roof pyrometer, right or wrong, will control everything except the stack damper.

It is therefore extremely important to have an instrument which is both accurate and above all reliable. We would much prefer an instrument which was 20° wrong at the start and not very sensitive, to one which was right but rather unstable.

I would like to support Mr. Robertson in stressing the need for continual supervision. In trials which we carried out recently at Templeborough, it was shown that not only was the photo-cell pyrometer an excellent instrument, but that if the attention paid to such an instrument during a comparison trial was also showered on the standard instrument very reliable results were obtained. There is no doubt that many deviations observed with roof pyrometers in the past can be directly traced to inadequate maintenance.

Particular attention must be paid to the water-cooling system. It is very easy in a steelworks, where water is used for many purposes, for the water supply to the pyrometer to be cut off without anyone knowing about it. If that happens for a long time, the effect on the pyrometer is so disastrous that the melter notices it, but if it happens only for a short time it is possible that it will not be noticed, but will affect the calibration and result in a roof melting, although according to the pyrometer it is at a reasonable temperature.

I should like to ask one question about the cell itself. Mr. Hall's data on the batch of 50 examined at the National Physical Laboratory were very encouraging. We should like to know whether we can take a new cell and put it straight into use without upsetting the calibration.

I think that on the question of " what we are measuring " there is one factor which has not been mentioned, but which should be borne in mind, and that is the size of the target. We know that there are very considerable variations in temperature across a roof, particularly with an old roof with holes in it ; but we are looking at a very big target, a circle about 5 ft. in dia., and that will tend to even out the errors.

The one thing that worries me about these various calculations of absorption by CO_2 and water vapour and other probable errors is that different people working with very different methods are getting checks which are within the limits of ordinary operating conditions. The most convincing example which we have had was during an investigation at Templeborough on roof life, when we set thermocouples at different depths in the roof. We had one initially right through, one at $11\frac{1}{2}$ in. from the back (*i.e.*, $\frac{1}{2}$ in. from the surface), one at 3 in., one at 6 in., and one at 9 in., and during the refining period, when conditions were steady, we got a smooth relationship for the temperatures plotted as a function of distance (from the hot face). We thus got the extrapolated surface temperature, using platinum/platinum–rhodium thermocouples as a standard. It checked with the reading of a total radiation pyrometer sighted on the same area within 10° C. Again, we have instruments made on quite different principles, such as the Land pyrometer and the total radiation instrument. On reading the roofs with optical pyrometers and making a comparison with these two recording instruments over as much as a month, the checks, other than those done at times which are not recommended, such as early in the charge, worked out with average differences of about 10–15° C., so that,

while there may be interfering factors, they cannot in the ordinary way be of a very high order.

Mr. **D. A. Oliver** (Messrs. Wm. Jessop & Sons, Ltd., Sheffield) : I have been gratified to see this instrument develop, first when the author was a senior member of my research staff and later in steelworks practice.

It is important to divide this subject under two headings. First we have the theoretical difficulties to which the instrument is heir, and secondly the practical compromises which can be made. Dr. Chesters has just said that he would rather have it less accurate and robust, in the sense of not wandering very far, than have it highly precise but occasionally temperamental. With that I am in entire agreement. I would also add that if it turned out later that one's choice of a particular spot in the roof was not ideal, then one can apply a practical check by running the furnace until the roof just drips in that vicinity and noting the reading, quite apart from that of pure calibration.

The Open-Hearth Instrument Sub-Committee, which has full automatic control of melting furnaces as its goal, is very interested in any links in the chain that lead to that end, and it looks as though this particular pyrometer may be an important contribution. The fact that absorption of CO_2 and water vapour is ignored by the instrument is a useful feature, but whether Mr. Hall's recent photographs equally ignore the same disturbing factors will doubtless emerge when he analyses his observations later.

Inventions can never happen to order, and it is very fascinating to see the chain of events that has led up to an instrument of this type. Be not misled by its simplicity, because it would have been easy to design a roof pyrometer which looked really complicated. The author started this work not with a view to dealing with roof-temperature control, but with a quite academic objective. The earlier work on the theory and performance of the barrier-layer cell provided just the right kind of background for subsequent developments.

Mr. Robertson referred to the contamination of compressed air in works by oil, and I would add water vapour and even water itself. That suggested the necessity of letting the air which clears the sighting tube impinge on a part of the instrument where even if the worst occurred the readings would still be reliable.

The elegant theory on page 572 has had other repercussions, and has been applied to a general study of heat transfer in the furnace, and finally the theory given on page 574 *et seq.* happened to have been thrashed out on a very much more tedious basis in connection with the cooling of liquid steel in ladles.

I am drawing attention to these steps because sometimes we are challenged as to what industrial research involves. Industrial research means that you pursue something mentally as clearly as you can, with as few fetters as possible, and you talk about the applications and the dividends afterwards. We can see here a very useful example of that process. The work started academically. It took a number of practical turns in various directions, and now the theory comes back again to estimate the likely errors. Already further extensions are in view. Moreover, I should like to add that this instrument effected savings during the first run on a furnace which paid for the complete development.

Mr. **M. W. Thring** (British Iron and Steel Research Association, London) : The roof of an open-hearth furnace is not a very good thing with which to calibrate pyrometers, but there is a tendency to regard it as an ideal target for this purpose. I hope that it will be possible to introduce an instrument on the melting stage which will be more suitable for calibrating pyrometers and checking them conveniently.

Mr. **D. Manterfield** (Messrs. Steel, Peech & Tozer, Sheffield) : I have been associated with a works trial of one of these instruments to which Dr. Chesters has already referred. I am a little dubious about how far I may anticipate a final report which is now almost complete, and about how far anything that I may say may be taken to be the opinion of the Sub-Committee rather than my own personal view. It may be of interest, however, to mention a few details additional to those mentioned by Dr. Chesters.

One of the author's instruments was installed through the back wall of a furnace sighted on the usual target area, just over the tap-hole, and a total-radiation instrument was sighted on the same target area from a similar position on the other side of the furnace. When the author's instrument was first installed it was fitted with an indicating micro-ammeter, and the total-radiation pyrometer had the usual recorder. A number of checks were taken regularly over a series of charges using a disappearing-filament pyrometer, and over that period the standard deviation from the mean difference between the author's instrument and the disappearing-filament instrument was of the order of 10° C. As a matter of interest, it may be mentioned that the radiation unit had a standard deviation from the mean difference of 17° C. These deviations, by the way, will include the errors of the optical pyrometer as well. We regarded these results in the circumstances as very good.

One thing, however, was lacking. For a melting shop an indicator was not satisfactory; we wanted a recorder. This was eventually installed; the instrument was fitted with an amplifier, a large-scale indicator, and a recorder for further testing, so that the tests would be directly comparable. The indications were very good on the indicator, but the recorder, owing to the extreme sensitivity of the author's instrument, gave a band of readings rather than a straight line. One or two alterations were made to it at the suggestion of the author and others, and finally a large condenser was fitted across the recorder which effectively damped out the excessive sensitivity while retaining sufficient sensitivity to record any real deviations in roof temperature.

We then had a little trouble with vibration in the amplifying unit, but a slight alteration eliminated this trouble, and we got a long series of excellent results as compared with the disappearing-filament pyrometer. Incidentally, we got good results with the total-radiation unit also.

With regard to the instrument itself, we found that it was extremely sensitive, which to some extent was a slight drawback; even slight flickers of flame were immediately registered, particularly when we had the indicating micro-ammeter in circuit.

We found, comparing these instruments, that there was very little to choose between them. They both required similar maintenance and adequate water cooling. During the period of very bad weather in the early part of the year, we were charging wet material on occasion and had considerable splashing. In spite of the compressed air unit we had to change several lenses in the author's instrument, but we also had to change several screens in the radiation unit. My personal opinion is that on the final results any comparison of the accuracy of these instruments was slightly in favour of the author's instrument, but the general finding of the committee was that in all respects there was very little to choose between the two. We regarded the instrument as very satisfactory.

Dr. **A. H. Leckie** (British Iron and Steel Research Association, London): There is one question which I should like to ask the author. It arises out of the excellent work done by Mr. Hall which has just been reported in connection with the variation of temperature across the roof. It would seem that the differences quoted by Mr. Robertson in the safe temperature, 1670–1680° C. with gas and about 1650° C. with oil, must be due to variation across the roof, because whilst the roof may be only 1670° C. where the pyrometer is sighted it may be hotter somewhere else. Would it be possible for the author to arrange for his pyrometer to scan the roof like a television camera, and so record the temperature of more than one place on the roof more or less simultaneously to give a band on the recorder? In that way the melting-shop manager would have a much better guide as to the true temperature conditions over the whole of the roof. The field of view may not be very great, but it might be an improvement on the practice of sighting on one point alone. There may be all sorts of practical objections to such a procedure, but in view of the importance of this matter, to which Mr. Robertson has referred, it might be worth while for the author and his colleagues to give a little thought to it.

Mr. **F. Steghart** (Tinsley Industrial Instruments, Ltd., London): I should like to comment on what Dr. Leckie has just said regarding the importance of covering during the measurement as large a proportion of the roof as possible. Instruments mounted on a swivel are likely to be affected by the great heat, and the water cooling of those instruments would be rather difficult. Generally speaking, I think that it might be easier to use a number of instruments and switch over from one instrument to another.

Mr. Manterfield has mentioned sensitivity. This term may lead to misunderstandings. The sensitivity was not altered, but the recorder in the amplifier circuit was damped by means of a condenser and thereby the speed of response of one particular instrument reduced. Speed is not very important on a recorder and, indeed, one with a lower speed may write more clearly than a high-speed recorder. As soon as control problems are introduced, however, high speed is a necessity to operate control apparatus or safety devices which are often incorporated in roof-temperature measuring equipment.

The photo-cell, according to the author's theories, has theoretical advantages over a total-radiation instrument, but it may be of interest to mention that there are now available total-radiation pyrometers the speed of which is as great as that of a photo-cell, so that if at any time it should be proved that it was more advantageous to use total-radiation instruments no difficulties would exist. The total-radiation instrument has another advantage, which is that it is not as sensitive to the failure of water supply as is the photo-cell since it will stand up to temperatures in the region of 200° C.

AUTHOR'S REPLY

Mr. **T. Land**, replying to the discussion, said: I should like to say how very much I appreciate the contribution by Mr. Hall, because I think he has brought to our attention in a graphic form the probable direction of our research programme for the near future. His photographs show the magnitude of the variations of brightness under different conditions and, as Dr. Leckie suggested, probably these variations cause the differences which Mr. Robertson has noticed between oil-fired and gas-fired furnaces. I think we are now passing out of the stage of developing instruments and into the stage of examining conditions of measurement.

The removal of oil and dirt from the compressed air, to which Mr. Oliver and Mr. Robertson have both referred, is of great importance and presents considerable difficulty. I might have explained that in the arrangement at Wm. Jessop and Sons, Ltd., there were two standard air filters in series, so that the air passed first through one and then through the other; also a hood was arranged over the lens so as to catch any fine mist of oil or water which passed the filters. That is necessary in order to have really satisfactory conditions of operation.

There is a point which Mr. Robertson mentioned which might lead to some misunderstanding, and that is the question of calibration. It is true that a well-designed pyrometer will retain its calibration for years to within 5–10°. There should be no difficulty in assuring such stability, but that does not mean that there should be no inspection. Some of the things which can cause errors have been mentioned in the discussion, such as splashes of metal on the lens, obstruction of the sighting hole, and so forth. Personally, I favour the use of two pyrometers placed side by side, sighting from separate holes close together on the back wall. The pyrometers would be connected to the same recorder, or two different recorders, and to a large indicator which would be switched automatically from one pyrometer to the other at frequent intervals. This arrangement has the great advantage that it shows up at once any obstruction to either of the instruments or any failure of one of the instruments.

Dr. Chesters has raised the question of cell interchangeability. This, I am afraid, is straying a little from the academic into the commercial aspect of the matter, but he may rest assured that, as the result of the N.P.L. calibrations of these cells, we fit each unit with a suitable resistance so that they are completely interchangeable.

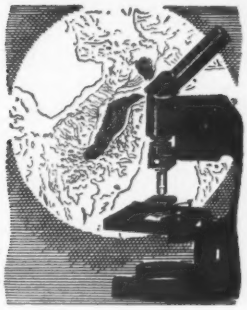
I was particularly glad to have Mr. Oliver's comments on this development, as it was under his direction and largely due to his inspiration that the development occurred at all, and I would draw the moral—which is very much the same as Mr. Oliver would say—that we should not lay down our research programmes too rigidly. A considerable measure of latitude should be left to the enterprise and interest of the individual, because quite often they lead to important practical developments. I can only say that it was due to Mr. Oliver's clear understanding of that principle that I was able to do any of the work that led up to the present paper.

I most certainly agree with Mr. Thring's remarks as to the use of the roof for the calibration of radiation pyrometers, particularly after having seen Mr. Hall's photographs. Mr. Thring did not say so, but I know that he is preparing at the Physics Department a standard source on which radiation pyrometers of different types can be calibrated and by which their characteristics can be examined, and I welcome that as one of the prime essentials today. After seeing Mr. Hall's pictures I am confirmed in my opinion that we cannot accurately compare the merits of different pyrometers by merely sighting them on the roof. I think that the errors due to the irregularities of the brightness temperature on the roof probably tend to swamp any difference between pyrometers. That means, not that we should not try to get better pyrometers, but that we need a good source for calibration.

Scanning the roof, as suggested by Dr. Leckie, may raise mechanical difficulties, particularly in the hot zone of open-hearth furnaces. I think that a number of pyrometers connected to a switching arrangement would prove more satisfactory.

B. I. S. R. A.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION



A Critical Survey of Wire-Drawing Theory

By G. D. S. MacLellan, M.A.

SYNOPSIS

This review of published work on some theoretical aspects of wire drawing is a further instalment of the survey described in the synopsis of J. G. Wistreich's paper on "Back-Pull Wire Drawing," published in the November, 1947, issue of the *Journal*.

It is concerned primarily with theories relating to the determination of the stresses in the wire during drawing. The errors and inconsistencies in many of these theories are pointed out, and a comparison of the more significant contributions is made. In addition, some ways of testing those theories which give results in reasonable agreement with experience are considered, and attention is drawn to some of the more important conclusions which can be drawn from them.

INTRODUCTION

WIRE drawing is a subject on which much uncoordinated research has been done in the last 25 years. As a first step towards clearing the way for further investigations, this paper provides a critical survey of the published theoretical work on the relation between the forces involved in wire drawing and measurable physical quantities. This approach appears useful, because although the theories involve many simplifying approximations and assumptions many of the observed effects in the process can thereby be accounted for. The imperfections of some of the attempts will be discussed and their conclusions compared, and finally, references will be made to the ways in which experimental work can most usefully be directed towards the further testing of those approximate theories which avoid all obvious inconsistencies and mistakes. A full discussion of the applications of recent developments in plasticity theory to wire-drawing is beyond the scope of this paper.

In order to shorten the review, all the distinct notations and definitions adopted in the past are not reproduced. The main aim is to give a connected account of the various theories, to draw attention to errors and inconsistencies, and to compare the relative merits of the different approaches. In this connection it must always be borne in mind that any useful theoretical analysis must ultimately be expressible in a form which can be tested experimentally and, furthermore, be capable of being extended to predict, with reasonable accuracy, results at the design stage of the drawing process.

HISTORICAL SURVEY

The main interest of investigators into wire-drawing theory has been in the dependence of drawing force and power on the various factors which have been known from an early date to influence it.

Lewis,[1] in 1915, was one of the first to attempt to formulate a relation between power requirements and the properties and dimensions of the wire, but he did not attempt to separate the various purely mechanical losses in the draw bench from the power actually used at the die. His final formulæ, both at this date and later, in 1933[2] and 1938,[3] involved empirical factors which varied with the fractional reduction of area over a range of about 2 to 1.

Otherwise, there appears to have been little interest shown in America, except for Elder[4] who attempted to extend Lewis' approach to take account of the measured strain-hardening characteristics of wires. Recently, however, Davis and Dokos,[5] in 1944, working virtually independently and starting again from first principles, have arrived at a somewhat complicated expression for drawing force in terms of wire dimensions, mechanical properties, die angle, and coefficient of friction; their analysis will be discussed at a later stage in this review.

In this country also, interest has been rather spasmodic. Horsburgh,[6] in 1930, made a number of simplifying assumptions, and obtained a solution which was followed up and compared with some experimental results by Thompson and Francis[7] in 1931. Since then there appears to have been no real further interest in the theoretical aspects of wire drawing until a recent publication by Lunt and MacLellan,[8] which extends the simple theory to take account of pre-stressing the wire as it enters the die.

There have been several attempts in Germany to provide a solution, but most of these depend on the accuracy of very restrictive assumptions, and Sachs' early publication,[9] in 1927, still seems the most useful.* It has fairly recently been extended, by Körber and Eichinger,[10] to take account of what they describe as internal frictional losses due to rotation of the

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* The German point of view has recently been summarized by Siebel.[31]

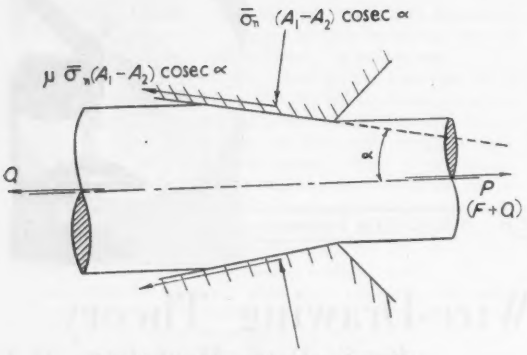

Fig. 1—Forces acting on the wire

principal strain axes at entry to and exit from the die. More recently again, Pöschl[11, 12, 13, 14] has proposed a solution involving a radical departure from accepted plasticity theory.

In addition there has been some Russian and Japanese interest in the problem, as shown by the work, for example, of Lashko[15] and Târo Uéda.[16] The contributions of these workers will be mentioned in the main outline of the development of the theory.

PLASTICITY CONDITIONS

The first stage in any attempt to derive a relation between the stresses in the wire-drawing process and the physical conditions governing it is a consideration of the conditions which govern the transition from the elastic to the plastic state. Even at the present time there appears to be very little known about the laws governing the plastic flow of metals when the deformations are appreciable compared with the original dimensions of the material, as in wire drawing; a single draft may here cause a uniform reduction of area of more than 40%, in an extreme case. The usual practice has therefore been to adopt the same criteria for the transition from elastic to plastic deformation as have been found to hold for circumstances in which the plastic deformations are small and of the same order as the elastic. These criteria have been adequately reviewed elsewhere,[17, 18] and it is sufficient, for the present purpose, to summarize the accepted results as follows:

> For ductile metals, the stress condition that agrees best with experimental evidence is the von Mises criterion. The other commonly used criterion, the maximum shear stress condition, in every example investigated experimentally, gives results of accuracy at least to within about 15%, *i.e.*, sufficient for most practical purposes. Other conditions, such as those of the maximum principal stress or the maximum principal strain, have been shown to give very erroneous results for conditions of combined stresses, such as occur in wire drawing, as far as the transition from elastic to small plastic deformations is concerned.

This last point is important, because in the most recent German contribution to the theory of the subject, by Pöschl,[14] considerable use is made of the maximum principal stress criterion in the analysis. This will be discussed further later.

One other point which simplifies the discussion as far as the axially symmetrical case of wire drawing is concerned is that the radial and the circumferential stresses in the deformation zone of the die must always be equal, on account of the equality of the corresponding radial and circumferential strains.[8, 11] In this special case, there can only be considerably less than 15% of error introduced by using the maximum shear stress hypothesis instead of von Mises' hypothesis. Thus if shear stresses due to friction are completely neglected, the two conditions are identical,[8] and for a coefficient of friction of as much as 0·2, an extension of the same analysis shows that the error is less than 6%. Such a variation is within the probable variation of the mechanical properties of the wire.

LIST OF SYMBOLS

A	= Cross-sectional area of the wire at any section.
A_1, A_2	= Values of A at entry to, and exit from, the die, respectively, neglecting elastic recovery.
F	= Resultant axial reaction on the die.
F_s	= Resultant force on one half of the die, in the plane perpendicular to the wire axis.
P	= Drawing force.
P_i	= " Ideal frictionless drawing force."
P_0	= Drawing force for special case of $Q = 0$.
Q	= Back pull.
Y	= Yield stress of the wire material at any section.
Y_1, Y_2	= Values of Y at entry to, and exit from, the die, respectively, neglecting ageing.
Y_m	= A mean value of Y.
b	= A dimensionless quantity characteristic of the effect of Q on F.
r	= Fractional reduction of area $\frac{A_1 - A_2}{A_1}$.
α	= Semi-die angle.
η	= " Drawing efficiency " (Pi/P).
μ	= Coefficient of friction between wire and die.
ν'	= The equivalent of Poisson's ratio for plastic deformation.
σ_n, $\bar{\sigma}_n$	= The normal stress, and its mean value between the wire and the die.
σ_z	= The axial stress at any section of the wire (assumed uniform across the section).

ELEMENTARY THEORY

Although it is impossible to progress far without considering the most appropriate way of incorporating the plasticity condition, a consideration of the elementary statics of the external forces acting on the wire does help to provide an initial common link for most of the theoretical work which has been done.

If $\bar{\sigma}_n$* represents the mean normal stress between the wire and the die (assumed purely conical, for simplicity), and $\bar{\mu}$* is the mean coefficient of friction between the wire and the die, resolution of forces parallel to the axis of the wire (*cf.* Fig. 1) gives:

$$P = (A_1 - A_2)(1 + \bar{\mu}\cot\alpha)\bar{\sigma}_n + Q \quad \ldots\ldots\ldots\ldots (1)$$

In this equation, A_1 and A_2 are the initial and final cross-sectional areas of the wire, α is the semi-angle of the die, and P and Q are the forward and backward forces on the wire, in the most general case of drawing with back pull. The extension of this general relation to cover curved die channels is straightforward, but does not lead to any very valuable result.

Equation (1) has, in effect, been the starting point of Lewis' numerous contributions[2, 3] to the theory

* The precise significance of $\bar{\sigma}_n$, and the average $\bar{\mu}$, can best be expressed as $\bar{\sigma}_n = (\int \sigma_n . dS)/S$, and $\bar{\mu}\bar{\sigma}_n = (\int \mu\sigma_n . dS)/S$, where S is the interfacial area between the wire and the die, of Lunt and MacLellan.[8]

of wire drawing. Unless somewhat drastic simplifying assumptions are made, however, it is not in a very manageable form. Firstly, although A_1, A_2, α, and Q are all measurable with some accuracy, $\bar{\mu}$ is a quantity for which there is very little independent and reliable data available. It is not possible to reproduce the conditions prevailing in a wire-drawing die on any existing friction-measuring instrument, and although it has normally been assumed that the wire–die interface is in a state of so-called " boundary lubrication," *cf.* Goodacre,[19] it is not unreasonable to suppose that at some of the higher drawing speeds used in modern practice the transition to fluid film lubrication may begin.

Secondly, even if the maximum shear stress criterion is accepted as a guide to the stress distribution in the wire in the deformation zone, there is no simple relation between $\bar{\sigma}_n$ and the mean yield stress of the wire.

Lewis avoided those difficulties by assuming in effect that $\bar{\sigma}_n$ was equal to the mean yield stress. He evaluated $\bar{\mu}$ for a large number of experiments in which the other variables were measurable, for mild-steel wire, and summarized his results in the form of a curve of $(1 + \bar{\mu} \cot \alpha)$ against fractional reduction of area r.[3] For this purpose he assumed that the mean yield stress of the wire was given sufficiently accurately by the initial ultimate tensile strength of the wire before drawing. In the result, however, he obtained values of $(1 + \mu \cot \alpha)$ ranging from 3·0 at 10% reduction to 1·2 at 50%. Such a variation in the effective value of $\bar{\mu}$ (for in a single conical die it must be assumed that α was constant) indicates the inadequacy of such a simplication of the theory.

The foregoing brief statement of Lewis' conclusions, as contained in his most recent publication[3] on that subject, ignores other approximations for $\bar{\sigma}_n$ proposed at earlier dates, and also gives only the essence of his arguments ; these were complicated by his efforts to make fuller allowance for such effects as the existence of a ' parallel ' in the die throat and work-hardening, and are discussed at length by Lunt and MacLellan.[8] More recently, Elder[4] has put forward an analysis similar to Lewis', but taking account of the shape of the stress/strain curve in the simple tensile test as a guide to the degree of work-hardening taking place. Here again, however, the form of the results requires an enormous and apparently unjustifiable variation in $\bar{\mu}$ to ' balance ' the equation.

It is also of interest to note that Weiss[20] in Germany, in 1922, outlined the elementary theory used by Lewis, although owing to some confusion in the analysis he obtained an expression containing cosec α instead of cot α. At a later date, in 1927, he attempted[21] to relate this theoretical approach to some experimental results, but he found it necessary to introduce an additional multiplying factor which varied very considerably with die angle and fractional reduction of area, to take account of " increased deformation resistance." Thus, once again the inadequacy of this over-simplified treatment is demonstrated.

Before leaving this aspect of the subject it is worth referring to one method by means of which μ and $\bar{\sigma}_n$ could be separately analysed. If not only the axial force on the die, but also the transverse force which acts so as to split the die laterally, is measured, μ and $\bar{\sigma}_n$ can be determined. Thus, if F_s is the transverse force, and F, *i.e.*, $P - Q$, is the axial die force, the following relations hold :

$$F_s = \bar{\sigma}_n(A_1 - A_2)(\cot \alpha - \mu) \quad \text{.....(2)}$$

$$F = \bar{\sigma}_n(A_1 - A_2)(1 + \mu \cot \alpha) \quad \text{.....(3)}$$

It follows, immediately, that :

$$\mu = \frac{F \cot \alpha - F_s}{F + F_s \cot \alpha} \quad \text{.....(4)}$$

and :

$$\bar{\sigma}_n = \frac{F + F_s \cot \alpha}{(A_1 - A_2)\operatorname{cosec}^2 \alpha} \quad \text{.....(5)}$$

There are at present, as far as is known, no published accounts of any work done from this point of view.

EARLY THEORY, WITH FRICTION NEGLECTED

If the effects of external friction and work-hardening were negligible and all metals had sharply defined yield points, the solution of the stress distribution in drawing would be greatly simplified. This point was realized at an early date, and one line of approach based on it has been followed up with interesting results.

Neglecting friction and work-hardening, and assuming that the maximum shear stress (or the von Mises) criterion holds even for large deformations, it follows[22, 23] that :

$$P = A_2 \int_{A_2}^{A_1} \frac{Y}{A} \cdot dA = A_2 Y \log_e \frac{A_1}{A_2}, \quad \text{.....(6)}$$

where Y is the supposedly *constant* yield stress of the metal. In deriving this equation the case of no back pull has actually been considered, but there is no significant change in the expression when back-pull is present. The net work done in drawing unit volume of wire in each case is the same.

It will be seen that this expression for P, which may be described as the ' ideal frictionless drawing force ' P_i, depends only on the initial and final dimensions of the wire and on its mechanical properties as described by its yield stress. It is independent of the shape of the die and, in fact, the work required would have been the same in the complete absence of a die.

A number of investigators have assumed that the force given by equation (6), is the theoretical ideal minimum, with Y taken equal to the initial yield stress of the wire before drawing, and have used it to compute the ' efficiency ' of the drawing process in any practical case. Thus the ' drawing efficiency ' is defined by the relation :

$$P_i = \eta P \quad \text{.....(7)}$$

The actual values of η cover a wide range, and as it is no simpler to express η, rather than P, in terms of the other variables which govern the drawing process, it would appear that little was gained by the introduction of this new symbol. This is no doubt true from the fundamental point of view, if a clearer understanding of the forces involved is required, but the use of η has certain merits as a practical guide to the

relative efficiency of area reduction involving different numbers or sizes of drafts and different dies. That is, although it is of little value in helping to predict the magnitude of the drawing force in advance, it may be of assistance in analysing the results of drawing experiments. Its further consideration from this point of view, however, lies outside the scope of the present paper.

An obvious simple extension of the expression for P_i is to replace the initial yield stress Y, by an average value Y_m which allows, to some extent, for the unavoidable strain-hardening ; such an average value would be the mean of the yield stresses of the wire before and after passing through the die. This does probably provide a better guide to the irreducible minimum drawing force, but as the final yield stress depends to some extent on how the reduction is carried out, *e.g.*, whether in one or two stages, the value of P_i modified in this way is no longer characteristic purely of the amount of the reduction.

EXTERNAL FRICTION, AS A SUPERPOSED EFFECT

It has long been realized that external frictional drag accounts for a very large proportion of the total drawing force, and that if this could be appreciably reduced very considerable power savings and, more especially, reduction in die wear and general wear and tear might be obtainable. The way in which external friction affects the drawing process has therefore always been one of the main objects of theoretical investigations. If it were to be found, for example, that the reduction of the effective coefficient of friction by a factor of 2 caused anything approaching a corresponding increase of the normal pressure between the wire and the die, one of the main objects in any scheme for improving die lubrication would disappear. That there does in fact appear to be an effect which tends in this direction, as is discussed below, shows that the theoretical analysis may lead to important results which would not otherwise be evident without much experimental work.

Sachs and van Horn have suggested, in their book,[23] that a convenient approximation which takes account of external friction is :

$$P = A_2 . Y_m . \log_e \frac{A_1}{A_2} . (1 + \mu \cot \alpha), \quad \ldots\ldots\ldots (8)$$

where here, as elsewhere in discussions of the theory, unless specifically stated otherwise, μ is supposed constant throughout the die. The derivation of this expression, however, involves assumptions about the behaviour of the wire in the die which are inconsistent. Thus, as far as the stress condition for plasticity is concerned, the additional stresses due to the external frictional drag are neglected, even though these may, in places, be of the same magnitude as the original stresses in the friction-free case. In a practical instance, μ might be $0 \cdot 1$ and $\alpha = 5°$, so that $\mu \cot \alpha = 1$, and so, according to equation (8), the tensile stress at the die exit would be doubled, on account of friction, with no corresponding change in the transverse pressure due to the die. The maximum shear stress condition, which requires the sum of the axial tensile and the transverse compressive stresses to be equal to the yield stress, would no longer be even approximately satisfied.

Slight variations from equation (8), which appear in most cases to be due to incorrect analysis of the forces involved, account for several other attempts at formulating a relation for the drawing force, and need little further discussion. In his book, Pomp[22] quotes the result given by Siebel[24] in 1926. For the purpose of calculating the superposed frictional drag, Siebel assumed that the normal pressure between the wire and the die was everywhere equal to Y_m. Apparently he did not realize the further inconsistency which this assumption immediately introduced, namely, that the force on the die was no longer equal to the force on the wire. An analysis based on this assumption should, by a straightforward resolution of forces, have led to an expression of the form :

$$P = A_2 . Y_m . \log_e \frac{A_1}{A_2} + (A_1 - A_2)\, Y_m . \mu \cot \alpha \ldots (9)$$

However, on account of further confusion in his consideration of the extra work done against friction, he finally obtained an expression of the form :

$$P = A_2 . Y_m . \log_e \frac{A_1}{A_2} . (1 + \mu \cot \alpha + \mu \tan \alpha) \ldots (10)$$

This, as it happens, is virtually the same as Sachs' and van Horn's approximate equation (8), because $\tan \alpha$ is in all practical cases negligible compared with $\cot \alpha$.

The errors leading up to this result have been dealt with in detail, because of their perpetuation in Pomp's book. The same result has, incidentally, been obtained in Japan, in 1939, by Târo Uéda,[16] apparently due to the same mistake. (The text of his paper is in Japanese, and it has only been possible to refer to his actual calculations and numerical results.)

In the discussion of these various expressions it is important to realize that for most normal reductions of area, $A_2 \log_e (A_1/A_2)$ is not greatly different from $(A_1 - A_2)$. Table I gives values of $(A_1 - A_2)/A_1$, *i.e.*, r, compared with the corresponding values of $(A_2/A_1) \log_e (A_1/A_2)$, *i.e.*, $(1 - r) \log_e 1/(1 - r)$, where r is the fractional reduction of area.

For 20% of reduction the difference is only about 10%, although beyond that, the error increases more rapidly. The use of $(A_1 - A_2)\, Y$ for the "ideal

Table I

COMPARISON OF GEOMETRIC AND NATURAL FUNCTIONS OF THE REDUCTION OF AREA

Fractional reduction of area, r	0	0·05	0·1	0·15	0·20	0·30	0·40	0·50
$(1 - r) \log_e \frac{1}{1 - r}$	0	0·0485	0·0946	0·138	0·178	0·249	0·307	0·346

frictionless drawing force" P_1, is therefore not unreasonable, and may in some cases be more convenient.

Before going on to consider how the frictional drag affects the deformation process itself, it is of interest to note one use of the above elementary theory in analysing experimental results. Linicus and Sachs[25] have published an account of extensive researches on the power requirements in drawing, in which an attempt was made to separate the external frictional drag from the "deforming force." The essential principle of their method was to make the resultant external frictional drag act in a direction inclined to the wire axis, by rotating the die as the wire was drawn. By a comparison of the axial components of the drawing force for different rotational speeds they attempted to obtain an estimate of the total effective frictional drag. By subtracting this from the drawing force for a stationary die, the "deforming force" was obtained. Although they managed to obtain some interesting results, the conclusions drawn from them are extremely doubtful, on account of the interdependence of the "deforming force" and the external frictional drag. This is illustrated by Sachs' analysis (*see* next section), and confirmed by the results of experimental work with back pull (*see* section on Back Pull). Furthermore, Francis, Greenwood, and Thompson[26] have found that under certain conditions the drawing force may even be greater with the die rotating than without, a result which cannot be explained reasonably in the light of this simple theory.

EXTERNAL FRICTION AND ITS INFLUENCE ON THE DEFORMATION FORCE

In 1927, Sachs[9] gave a theoretical analysis which appears to be a much better approximation to the actual conditions existing in the die, but the solution is in a form which is not very convenient for use with experimental results. The main assumptions in his approach were :

(i) That the maximum shear stress criterion governs the principal stress distribution.
(ii) That the surface frictional drag does not cause any appreciable variation of stress across the section of the wire, but that it is balanced at every section by a uniformly distributed axial tensile stress.
(iii) That strain-hardening can be neglected, and
(iv) That the coefficient of friction is everywhere the same.

Condition (i) gives the relation :

$$\sigma_z + \sigma_n = Y, \quad \ldots\ldots\ldots\ldots\ldots\ldots (11)$$

where σ_z is the axial tensile stress at any section, whose cross-sectional area is A, σ_n is the corresponding normal compressive stress between the wire and the die, and Y has the same meaning as before.

Condition (ii) leads to the following equilibrium equation for any section of the wire, by resolution of forces acting parallel to the wire axis :

$$d(A \,.\, \sigma_z) + \sigma_n(1 + \mu \cot \alpha)\, dA = 0 \ldots\ldots\ldots\ldots (12)$$

The solution of equations (11) and (12) can be expressed in the form :

$$P = A_2\, Y\, (1 + \frac{1}{\mu \cot \alpha}) \left[1 - \left(\frac{A_2}{A_1}\right)^{\mu \cot \alpha}\right] \ldots (13)$$

This relation was reached independently by Horsburgh[6] in this country, in 1930, and although his result appears superficially to be different, it is shown in one of Thompson and Francis' papers[7] to be the same. Lashko,[15] in Russia, also attempted a similar approach, but by resolving stresses at one point in his analysis, instead of forces, he arrives at an incorrect and still more complicated result.

The variation of $P/(A_2 Y)$ with r and $\mu \cot \alpha$ which is predicted by equation (13), is reproduced in Fig. 2, from Sachs' paper. The difficulty of applying the result lies mainly in the uncertainty of the appropriate values to be taken for μ and for Y, which has to be assumed constant through the die to obtain an explicit solution for P. No great use seems to have been made of the result in this form. It is quoted by Eichinger and Lug,[27] in 1941, in connection with some experiments on the heating-up of the wire and die during drawing. They include an additional so-called "internal friction term," which is discussed further below, but the whole expression is used only to determine μ. Using the arithmetic mean of the initial and final yield stresses for Y, they found values of μ ranging from 0·09 to 0·24, which are, at least, of reasonable magnitude. Although considerable further checking of the relation is necessary, it appears that if a value of μ of the order of 0·1 to 0·2 were adopted, equation (13) could be used, with more reliance than Lewis' equation, as a guide to the drawing forces required for any particular reductions.

The most noteworthy feature of equation (13) is the way in which μ is more or less inextricably interlinked with the other main factors, *viz.*, α and the wire areas, A_1 and A_2, which determine the drawing force. (As Sachs himself pointed out, however, when $\mu = 0$ the solution reverts to the logarithmic form of equation 6.) There is, therefore, from one point of view, at least, little to be gained by any attempt to split the drawing force into a "deformation" component and a "friction" component, as such. *Furthermore, the greater the actual reaction on the die due to the frictional drag, the smaller is the "deformation" component of the drawing force.*

This may be most easily seen by a comparison of equation (13) with equation (1) ; with $Q = 0$:

$$P = (A_1 - A_2)\,(1 + \mu \cot \alpha)\ \bar{\sigma}_n \ldots\ldots\ldots\ldots\ldots\ldots (1A)$$

This gives :

$$\bar{\sigma}_n = Y \,.\, \frac{A_2}{A_1 - A_2} \left\{\frac{1}{\mu \cot \alpha} \left[1 - \left(\frac{A_2}{A_1}\right)^{\mu \cot \alpha}\right]\right\} (14)$$

As μ increases, the term in {.....} brackets involving μ steadily decreases from the upper limit of $\log(A_1/A_2)$. That is, $\bar{\sigma}_n$ *decreases with increasing* μ. The reaction on the die due to friction, $(A_1 - A_2)\ \bar{\sigma}_n \,.\, \mu \cot \alpha$ (which is the most logical definition of the "friction component" of the drawing force), however, evidently also increases with increasing μ, because it is proportional to the [.....] bracket term on the right-hand side of equation (14).

Two conclusions can be drawn from this analysis. Firstly, when considered in conjunction with equation (2), which gives F_s as a function of $\bar{\sigma}_n$ and μ, it appears that F_s should decrease with increasing μ. This arises from the fact that practical values of α

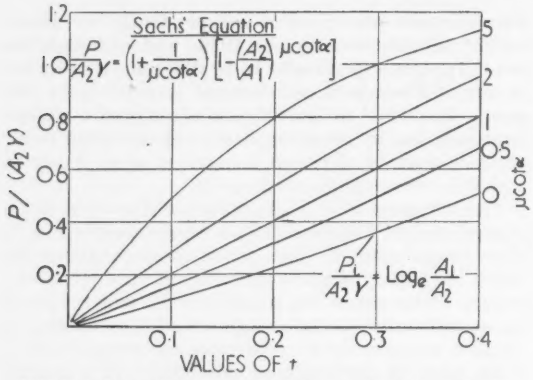

Fig. 2—Theoretical drawing force : Sachs' analysis

make cot α very much larger than any physically probable values of μ, and hence $(\cot\alpha - \mu)$ is almost independent of μ. F_s is thus approximately proportional to $\bar{\sigma}_n$ and should therefore decrease with increasing μ. That the effect may have an appreciable influence on the required transverse strength of the die can be seen from the following example :

Consider a reduction through a conical die having a semi-angle just less than 6°, so that $\cot\alpha = 10$. Then the ratio of F_s to F:

$$\frac{\cot\alpha - \mu}{\pi\,(1 + \mu\cot\alpha)},$$

as given by equations (2) and (3), varies as shown in the following :

μ	0	0·025	0·05	0·10	0·20	0·30
F_s/F	3·66	2·83	2·31	1·69	1·10	0·80

If the theory is a reliable guide, therefore, a reduction in the coefficient of friction from 0·10 to 0·05 means about a 40% increase in the transverse "splitting" force on the die.

The second conclusion concerns the rate of wear of the die channel. From equation (14), the average shear stress at the interface, $\mu\,.\,\bar{\sigma}_n$, increases with μ, but at a slower rate. Thus a reduction of μ by a factor of 2 may mean a reduction of the mean interfacial shear stress by only 20 or 30%, and a correspondingly small reduction of the average wear. However, the critical points in the die, from this point of view, are at entry—where the phenomenon known as "ringing" occurs—and at the die throat. "Ringing," which is the formation of a heavily worn area round the section where the wire first comes into contact with the die, is likely to be much more sensitive to μ. At this section the normal pressure must always be equal to the yield stress (minus the back-pull stress, if any), and thus independent of μ. Hence an increase of μ here means a proportional increase of interfacial shear stress. At the throat, an increase of μ will normally, according to Sachs' theory, mean an increase of interfacial shear stress, though under certain conditions of large μ and r there might be a decrease.*

* This can be shown by differentiation of an equation derived from equation (13). The critical condition of maximum shear stress at the throat occurs for :

$$\log\left(\frac{1}{1-r}\right) = \frac{1}{1+\mu\cot\alpha};$$

e.g., for $\mu\cot\alpha = 1$, $r = 0{\cdot}39$, and for $\mu\cot\alpha = 0{\cdot}5$, $r = 0{\cdot}49$.

EFFECT OF WORK-HARDENING

Recently there have been two extensions of wire-drawing theory along the lines used by Sachs, which show promise. Firstly, Davis and Dokos[5] have attempted to generalize the analysis to some extent by considering how the yield stress varies through the die, and inserting appropriate additional terms in the solution. Secondly, Lunt and MacLellan[8] have attempted to obtain a clearer insight of the effect of back pull, and have obtained a theoretical relation between P and Q which avoids any consideration of the precise way in which the yield stress varies through the die.

The main contribution of Davis and Dokos is the suggestion that the variation of yield stress can be most appropriately represented by a relation of the form :

$$Y = Y_1 + 3\,\Omega\,.\log_e\frac{A_1}{A}, \quad \text{.....(15)}$$

where Y is the yield stress at the wire section where the cross-sectional area is A, and Ω is a constant with the dimensions of a stress. This relation assumes that the maximum shear stress, in the maximum shear stress criterion, is a linear function of the maximum principal natural shear strain, an assumption which is shown to be fairly closely true for mild steel and copper in the ordinary simple tensile test, and which it is claimed on the strength of earlier work, holds regardless of the state of combined stress.

When equation (15) is combined with Sachs' equations (11) and (12), the following complete solution is obtained :

$$P = \left(1+\frac{1}{\mu\cot\alpha}\right)\left\{\left[1-\left(\frac{A_2}{A_1}\right)^{\mu\cot\alpha}\right]\left(1-\frac{3\Omega}{Y_1\,\mu\cot\alpha}\right) + \frac{3\Omega}{Y_1}\,.\log_e\frac{A_1}{A_2}\right\} \quad \text{.....(16)}$$

In the original form of the equation, given by Davis and Dokos, an additional term is included, due to "the stress at the boundary between the elastic and plastic ranges" at entry to the die. As this term is neglected at a later stage in their discussion, and as they do not attempt to account for its existence in terms of the statical equilibrium of the corresponding section of wire, there appears to be no useful purpose in reproducing it here. The variation of P with μ and the fractional reduction of area which is predicted by this equation is reproduced from their paper in Fig. 3, for comparison with the results given by the straightforward Sachs equation, which are given in Fig. 2.

Several comparisons of theoretical results, using equation (12) with the additional "elastic" term included with their own experimental data are given in their paper. The values of μ which have to be adopted to make the theoretical and experimental curves fit, range from 0·16 to 0·40. In addition it has to be supposed, for the sake of the theoretical equation, that there is a tensile stress of anything from 1200 lb./sq. in. for copper to 12,000 lb./sq. in. for mild steel in the wire as it enters the die, although the wire is drawn without back pull. This result

clearly shows certain limitations in the theoretical equation, but in fact, over the normal practical working range of reductions of area, there is no obvious reason why the relation should not give reasonable results. The simplest explanation of the anomalous results would appear to be the existence of a " parallel " in the dies, greater in the case of the dies used for steel drawing than for copper. This would probably cause an additional drag on the wire, decreasing as the amount of reduction increased, and giving an effect similar to that for which Davis and Dokos were trying to account. Once again, however, an essential limitation is the need to determine μ by trial and error.

It is worth adding that recently attempts have been made to generalize Sachs' equation still further by considering the effect of a curved die channel, in which α varies through the die. The results are of considerable complexity, and it seems doubtful whether any useful practical advantages are to be gained from extensions in this direction at the present time.

NON-HOMOGENEOUS DEFORMATION

Apparently, partly as a result of an attempt to correlate Sachs' theoretical drawing force equation with experimental results, Körber and Eichinger,[10] in 1940, published an account of the result of considering one other factor in the deformation process. They point out that at the wire sections where the reduction of area commences and ends, there is a sudden rotational distortion of the metal crystals. That is, except for volume elements situated right on the wire axis, the direction of the greatest principal strains are not parallel to the wire axis but directed towards the die cone vertex. It is therefore supposed that volume elements situated at a radius from the wire axis which subtends an angle ϕ from the wire axis at the cone vertex, undergo a shear ϕ both at entry and exit. By integration over the whole wire section, they finally conclude that there should be an additional term, of magnitude :

$$A_2(Y_1 + Y_2)\ \frac{2}{3\sqrt{3}}\ \alpha,$$

included in the expression for drawing force. With the addition also of a term to allow for back pull (*see* next section), their final expression, rewritten in the present notation, is equivalent to :

$$P = A_2 Y_m \left(1 + \frac{1}{\mu \cot \alpha}\right)\left[1 - \left(\frac{A_2}{A_1}\right)^{\mu \cot \alpha}\right] + A_2(Y_1 + Y_2)\ \frac{2}{3\sqrt{3}}\ \alpha + Q\left(\frac{A_2}{A_1}\right)^{1 + \mu \cot \alpha} \quad \ldots(17)$$

Körber and Eichinger do not in fact distinguish between Y_m, the appropriate mean value of the yield stress which has to be assumed constant to obtain Sachs' solution, and $\frac{1}{2}(Y_1 + Y_2)$, but the distinction is implicit in their analysis. Also, in practice, unless a graphical method is used to obtain Y_m accurately, it is clearly most conveniently approximated to by $\frac{1}{2}(Y_1 + Y_2)$.

The additional term due to this non-homogeneous deformation at entry and exit, or " internal friction " as it has been confusingly called by the German investigators, does account in a relatively simple way for an observed slight increase of drawing force with large die angles, *e.g.*, Linicus and Sachs.[25] It introduces inconsistencies, however, and the physical justification for it also appears to be to some extent doubtful in terms of recent plasticity theory. Thus the superposition of this supposed additional drawing force must change the distribution of stress on the die wall—precisely how, it is not easy to imagine—in order that the die reaction should continue to balance the net drawing force. In any case, Sachs' basic assumptions would no longer hold. It would appear that the explanation of the die-angle effect is only to be found in terms of a more comprehensive analysis of the exact mechanism of the deformation process in the die.

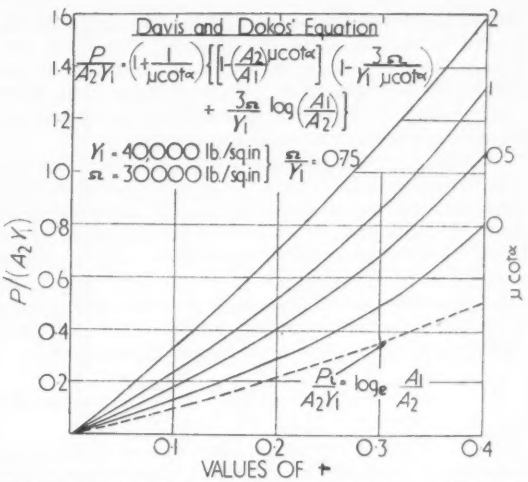

Fig. 3—Theoretical drawing force : Davis and Dokos' analysis

BACK PULL

One feature which is common to all the attempts, so far discussed, which have been made to obtain a theoretical relation for the drawing force, is that in order to evaluate the coefficient of friction some convenient average for the yield stress has to be assumed. If the resulting value of μ lies, say, in the range 0·05 to 0·30, it is considered that the formula is a reasonable approximation to the truth, and various other conclusions can safely be drawn from the results. In other words, the major difficulty in testing any new wire-drawing theory is that only one force is easily measurable—the reaction on the die—but there are two unknown quantities which are indeterminate by any other means, *viz.*, the coefficient of friction and the relevant average yield stress. Back-pull experiments have now, however, indicated a more promising line of approach.

Considerable attention has recently been given to the subject of drawing pre-stressed wire, but until the recent paper of Lunt and MacLellan[8] no serious attempt had been made to extend wire-drawing theory in detail to account for the surprisingly simple linear relation between the reduction in the die reaction and the amount of back pull. Certain published

results had tended to show that the physical relation might in fact be more complicated, but Lunt and MacLellan have examined this data, and carried out further tests themselves. They conclude that these variations from the linear law are due to inadequate control of the experimental conditions.

Without having to assume any particular law for the variation of Y through the deformation zone, they obtained an expression relating the drawing force with the back pull, which, except for μ itself, involved only directly measurable quantities. By a simple extension of the analysis given in their paper, for the present review their result is most conveniently expressed in the following form, which reveals a linear dependence of P on Q for any given draft.

$$P = P_0 + Q\left(\frac{A_2}{A_1}\right)^{1+\mu\cot\alpha} \quad \text{.....(18)}$$

In this, P_0 now represents the drawing force in the absence of back pull, *i.e.*, $Q = 0$. It will be seen that equation (18) is similar to the result previously obtained in effect by Körber and Eichinger, and reproduced here as equation (17). It has, however, here been generalized to stress the fact that variations of Y should not affect the linear dependence of P on Q. Furthermore, Körber and Eichinger were apparently not concerned with the possibilities opened up by this interpretation of the results of back-pull experiments.

Usually, instead of P, it is in practice more convenient to measure the reaction on the die seating, F, where $F = P - Q$, and experimental results are then expressible in the form :

$$F = P_0 - bQ \quad \text{.....(19)}$$

A comparison of equations (18) and (19) leads to the following explicit relation for the coefficient of friction :

$$\mu\cot\alpha = \frac{\log(1-b)}{\log(1-r)} - 1 \quad \text{.....(20)}$$

A theoretical solution has thus been obtained, using only certain generally accepted assumptions, which firstly accounts for the established variation of P with Q in a simple way, and secondly enables one of the two uncertain quantities in the general theory of wire drawing to be determined by direct experiment. The further investigation and testing of this relation with respect to experimental data lies outside the scope of this review, but it is necessary to point out that the correctness of the above theory cannot yet be regarded as finally established. If, however, the consequences of the theory are followed up, several interesting results appear which should be capable of independent verification, *e.g.*, the suggested *increase* of " splitting " force with reduced μ, mentioned in the section on external friction (p. 352).

PÖSCHL'S THEORY

There is one other independent approach to the theory of wire drawing, the discussion of which has deliberately been kept separate in this review. Although it introduces some interesting ideas, the main analysis departs radically from any generally recognized theories of plastic deformation without any real justification even by its results.

In a series of four papers published in Germany in 1942/44 Pöschl[11, 12, 13, 14] has developed a theory of wire drawing, apparently largely without consideration of whether the results of the analysis are in accordance with experimental results. He was challenged on this point by Siebel,[28] after the publication of the third of his series of papers. Siebel points out, amongst other things, that Pöschl's expression for the drawing force implies its steady increase with die angle—in contrast to the initial rapid decrease found by experiment—and that the tensile stress in the outgoing wire is always at least equal to the yield stress, though experiments show that it remains below this stress for even as much as a 25% reduction of area.

Pöschl does not attempt to meet these criticisms directly, in his fourth and final paper, which has been published in abstract form in this country,[14] but does in fact modify his expression for the drawing force, without any apparent justification, so that both of these anomalies, in effect, disappear. Although Pöschl only gives numerical examples for his final theoretical relation, the following appears to be the modified general equation corresponding to his latest analysis :

$$P = A_2 Y_1 2\,\frac{2-\nu'}{5-4\nu'}\left[1 - \tfrac{1}{2}(1-\nu')(1-2\nu')\,\alpha^2\right]\left[\left(\frac{A_1}{A_2}\right)^{\frac{1}{2}(5-4\nu')} - 1\right] \quad \text{.....(21)}$$

In this equation, ν' represents the plastic equivalent of Poisson's Ratio, and Y_1 has been identified with Pöschl's quantity $\sigma_\vartheta^{(s)}$, the yield stress of the wire where it is in contact with the die at entry to the die channel. In his later numerical examples a value of 0·48 is assumed for ν' instead of the generally accepted value of 0·5, as a result of some work of Plank[29] on the change of density of material undergoing plastic deformation. The derivation of equation (21) involves, incidentally, the reasonable assumption that α^4 is negligible compared with α^2 (α measured in radians) ; in fact, with $\nu' = 0{\cdot}48$, and practical values of α ($< 0{\cdot}4$), even the α^2 term is negligible.

It will be noted that the equation does not involve a coefficient of friction, and therefore suggests a

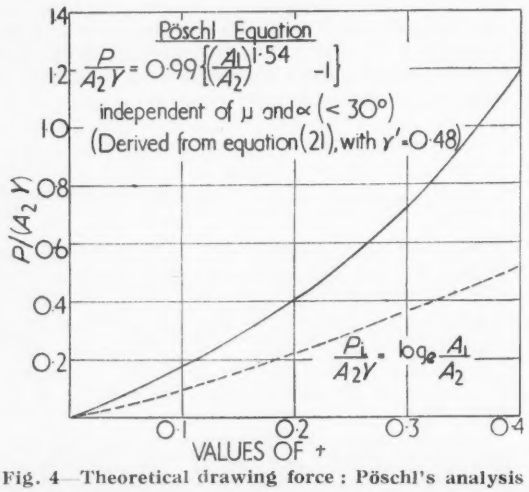

Fig. 4—Theoretical drawing force : Pöschl's analysis

drawing force independent of lubricant or the state of the die. The analysis does, however, assume the existence of a mathematically determinate surface shear stress at the wire–die interface. The general relation, corresponding to his analysis, for the coefficient of friction at any point of the interface is extremely cumbersome.

In Fig. 4 are plotted values of $P/(A_2\,Y)$ corresponding to equation (21) with $\nu' = 0{\cdot}48$, against the fractional reduction of area. Some typical values of μ corresponding to the complete analysis are given in Table II.

The only justification of Pöschl's departure from accepted views on the theory of plasticity, would be theoretical results which agree with experiment. It is, therefore, perhaps of some interest to note that equation (21) does represent a relation which corresponds almost exactly to that given by Davis and Dokos' equation, for the value of $\mu \cot \alpha = 0{\cdot}5$. As the relation is otherwise independent of μ and α, it cannot be regarded as of general application, for the lubricant and the shape of the die have been shown by various experimenters to affect the drawing force appreciably. Similarly, the results for μ, given in Table II, show, for the various die angles, a variation from one end of a die to the other for which there is no satisfactory physical explanation.

The main interest of Pöschl's work is his use of 3-dimensional co-ordinates for the analysis of the stress distribution. This is a considerable extension of the method outlined in the appendix of Lunt and MacLellan's paper,[8] and in the more trustworthy analysis of the stress distribution in the elastic state, which is dealt with in the first of the series of papers, are revealed some of the complexities of a full and accurate analysis. It does, however, appear that a solution to the problem of the force required to *initiate* plastic deformation might be obtainable along these lines. Nevertheless, it is important to realize that there must always be a distinction between the drawing force which is just sufficient initially to cause the plastic state to prevail throughout the die, and the drawing force which is required to maintain the deformation process when steady drawing conditions have been established, with work-hardening having an important influence on the later stages of the deformation.

Table II

Values of μ, Obtained from Pöschl's Equation, Corresponding to Progressive Stages of Reduction of Area in a Die, for different Die Angles

Fractional Reduction of Area, r	Values of μ for different Die Angles			
	26½°	11°	5°	3°
	cot $\alpha = 2$	cot $\alpha = 5$	cot $\alpha = 10$	cot $\alpha = 20$
0	0·29	0·10	0·045	0·027
0·05	0·31	0·11	0·049	0·029
0·10	0·34	0·12	0·053	0·032
0·20	0·41	0·14	0·064	0·038
0·30	0·49	0·17	0·078	0·046
0·40	0·62	0·22	0·099	0·059

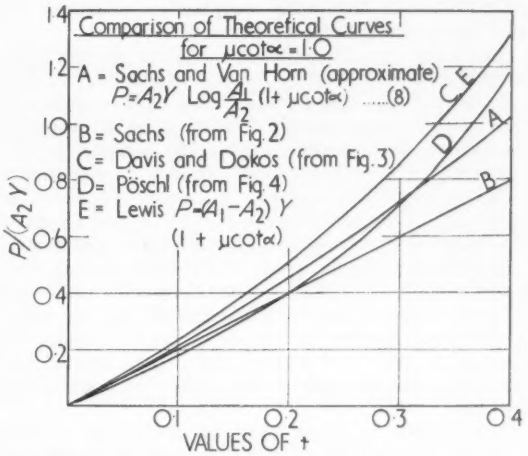

Fig. 5—Comparison of theoretical drawing force analysis

This distinction does not appear to have been expressly stated anywhere before and it is therefore perhaps worth noting that one early attempt, by Becker,[30] to obtain a solution does involve an approach of this kind. Becker considered that it might be possible to regard the deformation zone in the wire as part of a thick spherical shell. He neglected friction and his condition for plasticity was merely that, at the inner surface of the "shell" the maximum shear stress should be equal to the yield stress. His result is of no more than historical interest now, with Pöschl's more elaborate analysis available.

GENERAL DISCUSSION

This review has been concerned solely with a survey of published work on the theory of wire drawing. There have been considerable advances in the general theory of plasticity of metals in recent years, in relation to other plastic deformation processes, but it would lengthen this paper too much to attempt to discuss their relevance to wire-drawing theory. It is unlikely, however, that a wholly satisfactory complete solution to the wire-drawing problem will be found until these results are considered. Whatever form of solution results it is likely to involve graphical or computational methods, and therefore to be too laborious for use outside the research laboratory.

A direct comparison of the $P/(A_2\,Y) - r$ curves which result from the various published theories discussed above reveals some interesting results. Such a comparison is made in Fig. 5, where a value of $\mu \cot \alpha$ equal to 1·0 has been assumed. In making this comparison it is necessary to bear in mind that as far as the Davis and Dokos equation is concerned, Y must be taken to refer to the *initial* yield stress, although for the others a *mean* yield stress is usually assumed. The shapes of the curves only change if different values of Y are assumed for different values of r.

Firstly, even the least detailed theories, such as Lewis' or Sachs and Van Horn's, give curves which do not differ greatly in general form from those

resulting from the more complicated relations, for the physically realizable range of r.

Secondly, for the particular relative values of σ_n and Y assumed in the derivation of the curve based on Davis and Dokos' equation, this curve and Lewis' one (based on equation 1 with $\bar{\sigma}_n = Y$) coincide within 2% over the whole range of r considered.

Thirdly, Sachs and Van Horn's approximate relation (equation 8) gives a curve (A) which is more or less the mean of the curves (B and C) given by Sachs' original equation (13) and Davis and Dokos' equation (16), respectively. In other words, this approximate solution does in effect allow for some degree of work-hardening superposed on the effect of external friction on the deformation process, although it is in fact worked out on the assumption that external friction does *not* affect the deformation process.

The similarity in the shapes of all the curves draws attention to one other point. Even the more detailed theories of Sachs, or Davis and Dokos, do not account for Lewis finding that he required to stipulate a variation of $(1 + \mu \cot\alpha)$ over a range of 2·5/1 to account for his experimental results when using his simple equation. A possible explanation is that the materials which he used had very different work-hardening characteristics from those assumed in the numerical example of Davis and Dokos' equation given here. There is insufficient data given in his papers to settle this point finally, but it is proposed to give a full discussion of Lewis', and other experimental data in relation to these drawing theories in a later paper.

As far as immediate further experimental work is concerned, the most important objective is to confirm the significance of the values of the coefficient of friction μ found by means of back-pull experiments, based on the Lunt and MacLellan method of analysis. The experimental method suggested is by the use of a "split die," as described in the section on elementary theory (p. 349), and it is on these lines that further work is now being done.

If the physical significance of μ can be established in this way, it will provide the very necessary confirmation that a theoretical approach on the lines first begun by Sachs, and extended by Lunt and MacLellan, can usefully be adopted. The relative merits of the various approximate theoretical expressions described in this paper can then only be determined by careful measurements of the variations in yield stress of wire as it is drawn, and their relation to changes in the drawing force. In this way the most suitable function of the varying yield stress to adopt for use in any theoretical expression can be decided. Unfortunately, there exists very little published data relating to this variation of drawing force with change of yield stress. Most attention in the past seems to have been directed towards finding a simple relation between drawing force and the initial ultimate tensile strength of the wire. The latter quantity is perhaps the most easily measurable of all the mechanical properties of wire, being merely the load required to break the wire divided by its original area, but there is no obvious reason why this somewhat arbitrary stress—it does not even represent the true stress at fracture—should directly control the drawing force or even bear a unique relation to the yield stress.

Acknowledgments

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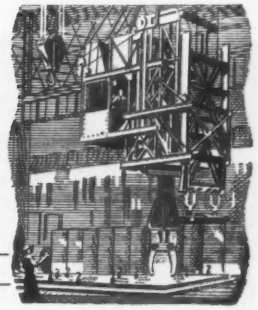
IRON AND STEELWORKS ENGINEERING



THE IRON AND STEEL ENGINEERS GROUP

Electric Control Gear for Steel-Mill Auxiliaries

By R. A. West, B.Sc.(Eng.), A.M.I.E.E.

SYNOPSIS

The paper, which is in ten Sections, refers to D.C. systems and general principles only. In Section I the author describes the functions of circuit-breakers, isolators and contactors and discusses the design and maintenance of their contacts. Section II deals with the various methods and advantages of dust exclusion and enclosure for contactor-gear panels in steelworks. In Section III the various methods of controlling the acceleration of electric motors are discussed. Section IV describes various applications of time- and current-limit systems to steel-mill equipment. In Section V the author reviews the factors affecting the choice of field windings for mill-auxiliary motors and methods of electric braking. Section VI discusses the use of graduated braking on steel-mill cranes and floor plant and Section VII contains a description of the application of inductive time-limit control to a ladle-tilting winch. In Section VIII the author discusses the use of Ward-Leonard control on steel-mill auxiliaries, and in Section IX he considers diverter-control of series motors with special reference to ingot bogies. Section X is devoted to a discussion of dynamic control on series motors and its application to steelworks equipment.

SECTION I—CIRCUIT BREAKERS, ISOLATORS, AND CONTACTORS

COMPARISON OF FUNCTIONS

A CIRCUIT-BREAKER is required to carry its full load rating continuously but it must be able to break an enormous current in an emergency. In many cases it is essential that it shall be able to handle the maximum short circuit kVA. which can take place over that portion of the electrical system which it protects. It should break circuit under these conditions without damage either to itself or its surroundings.

An isolator requires to carry its rated load indefinitely but does not have any guaranteed performance when opening under load. In fact it is well known that in many cases an attempt to open an isolator on load will destroy it.

A contactor is essentially designed for frequent operation. It is not designed primarily to carry its full rating for an indefinite period though it is occasionally required to carry out this duty : it is definitely not supposed to break under short-circuit conditions of great magnitude. The interrupting capacity of contactors is between 6 and 10 times their continuous rating at full voltage. On medium voltage D.C. circuits and overhead cranes in particular, the short-circuit conditions are not arduous owing to voltage drop in the system. A single-pole 200-amp. mill-duty (150 amp. continuously rated) D.C.contactor similar to Fig. 2 can break 1500 amp. repeatedly at 460 V. on a plain resistance load where all the volts appear in the arc as the current is extinguished. The breaking capacity is of course considerably increased when two contactors operate in series, one on each pole, as in the usual crane protective panel.

Contactor designs are in fact based on an assumed mill duty of 600 operations per hour or five million per year. They are the most efficient means of starting, stopping, and reversing electric motors. Drum controllers and other hand-operated switchgear become costly in maintenance when used frequently ; also the operator requires knowledge of how to use them and can only too easily increase the maintenance bill by ill-advised operation. An example of the efficient continuous service that can be rendered by automatic control gear without human supervision is the hydraulic accumulator.

COMPARISON OF RATING

An isolating switch of ordinary blade and clip construction is rated at 40–100 amp./sq. in. The brushes of a D.C. circuit-breaker are designed usually for the region of 250 amp./sq. in. In the case of a contactor the current is carried by a spot weld which would be barely $\frac{1}{8}$ in. diameter for the 200 amp. unit. That corresponds to a rating in the region of 12,000 amp./sq. in.

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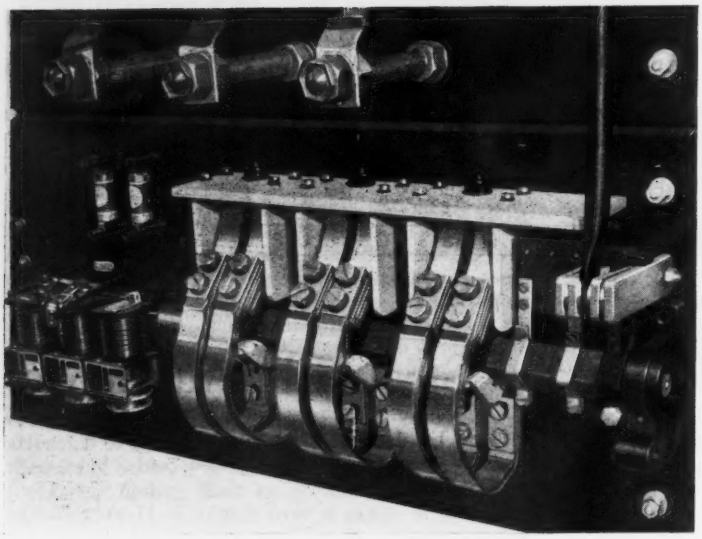

Fig. 1—Brush-type isolator

ISOLATORS ON CONTACTOR GEAR

Built-In Isolators

Increasing importance is now being placed upon the provision of an isolating switch which is built in to the contactor cubicle and provided with an external operating handle interlocked with the doors so that they cannot be opened unless the isolator is first opened. In the early days of automatic control the emphasis was on the phrase " automatic starting " and so it was customary for a separate switch fuse to be provided by the installation engineer. On important plant an internal isolating switch would be provided for convenience on the automatic panel and would be of the familiar blade-and-cross-bar pattern. A demand developed for externally-operated switches and little difficulty was encountered in connecting a mechanical lever system to operate this same type of switch in the smaller sizes. Larger apparatus retained the internal switches. As the demand increased so various attempts were made to reduce the effort for operating the larger switches by bringing nearer together the pivot point of the switch and the clips, whose considerable pressure made this type difficult to operate.

Brush-Type Isolators

The problem of providing efficient external operation for isolating switches has been found particularly acute. Laminated brushes operated by a toggle motion on the lines of the conventional D.C. circuit-breaker are now being used for large-capacity isolators. They are standardized in 300, 600, and 1200 amp. sizes (continuously rated) both double and triple pole. It is interesting to note that a double-pole switch of 600 amp. can be opened and closed easily by means of its external operating lever with the use of the index finger only.

Figure 1 shows a triple-pole brush-type isolator in the closed position with the shrouds in position for preventing accidental contact with the live parts when the isolator is open. Just to the left of the toggle mechanism can be seen a small contact board which carries the auxiliary poles. These may be required either for isolating a supplementary control-circuit supply, for eliminating the risk of a sneak circuit when the contactor panels have sequence interlocks between each other or, more usually, for ensuring that the contactors break the circuit if the isolator is opened on load.

CONTACTOR CONTACTS : ADVANCES IN DESIGN

Early Contactors

In spite of inadequate contact surface, surprisingly large currents can be carried by a pair of copper tips butting together. It was soon found that troubles with overheated tips were prevalent when heavier contactors were made. Consequently these were fitted with a laminated copper brush in order to back up the copper tip and arranged so that the brush circuit was cleared before the butt-tips separated. It can be easily seen that failure to maintain the copper tip will destroy the brushes. For severe duty cycles it was soon found that the back-up brushes gave more trouble than could be tolerated and this design was superseded by improved types of contactors which depended only on the carrying capacity of the butt-tips.

Contact Welding

Contactors when new appear to carry current

Fig. 2—Accelerating contactor of modern arc-transference type

through a line contact of negligible area operating under considerable pressure. Research has shown that the current is in reality carried by a spot weld. Consequently the necessary size is not determined by the breadth of the contact but firstly by its mass and that of the heavy metal parts to which it is firmly attached. It is this which effectively conducts the heat away from the spot weld at which it is generated. Secondly, the size of contact is influenced by the ability of the surface of the aforementioned mass to radiate and of the surrounding air to convect the heat away. The contacts, therefore, do not increase in width according to their capacity, their weight being more nearly proportional.

In order to break the weld, the design of the contactor must be arranged so that the contact spring will provide the maximum torque. Consequently, the nearer the final point of contact can be made to the fulcrum of the contact knuckle, the greater the torque for a given spring pressure. This is the reason for the basic features of a first-class modern contactor : these are two pivot points, that of the armature hinge and that of the contact knuckle, and a relatively short distance between contact point and contact pivot. The spring pressure is made as high as possible, consistent with avoiding too much batter and mechanical wear on the copper.

For heavy duty, therefore, the back-up brushes disappeared and larger butt-type contacts with strong contact springs came into being.

Improvements in Blow-Out Design

This type of contactor gave good service, but consumed copper rather quickly. The action of the magnetic blow-out was then examined more critically and minor improvements in the construction of blow-outs resulted in the copper tips being consumed at about a half or a third of the former rate.

Within the last decade, a further advance has been made in lengthening the life of the copper tips ; Fig. 2 shows a resistance contactor of the latest type which has a tail on the armature, by means of which an inductive time-limit lockout can be obtained. The copper fixed contact tip is mounted upon a very heavy bronze casting. The moving contact tip on the other hand falls into ambush behind a heavy bronze casting which is supported between the cheeks of the arc shield. This casting is electrically connected to the moving contact tip *via* suitable fixed connections, so that the arc is able to transfer itself from the tip to the casting when the former retires into ambush behind the latter. Thus, when the circuit is broken, the blow-out in the usual way forces the arc across the surface of the copper tips away from the body of the contactor and out on to the bronze castings. The path of the arc is extended in this process and the mass of the castings provides much cooling. The castings do not suffer from arc erosion owing to the cooling effect and the rapid interruption of circuit which the new blow-out design ensures. By this means the life of copper has again been trebled.

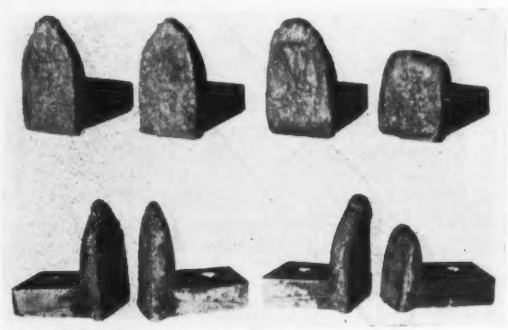

Fig. 3—Partly worn main contacts

Use of Silver for Continuous On-load Running

The heat developed at the junction of the contacts is much greater on contactors than on isolators and copper oxide is easily formed. A rolling slide action between the point at which the contacts touch initially and the point of final contact somewhat nearer to the contact pivot is therefore provided. Copper-tipped contacts should not be left closed for more than 6 hr. continuously unless the load is small for most of the time.

Silver oxide is thermally unstable at temperatures not much in excess of normal atmospheric conditions so that any tendency for the oxide to interfere with the conducting properties of the contacts is quickly dispelled by the attainment of normal working temperature. When, therefore, contactors have to remain closed for long periods in their normal duty and have to carry much current for most of the time, a plate of silver is brazed on to the surface of the contact.

Maintenance of Main Contacts

The distance through which the moving contact is rolled back, as the contactor closes, between first touch and final position is called the follow-through of the contact. Contactor tips should be renewed before this follow-through is reduced by wear to zero. Failure to do so will cause a contactor to weld in. This is one good argument in favour of having more than one line-break on any important plant.

It cannot be too strongly stressed that the tips of main current contactors should not be filed as part of routine maintenance. Tips bed themselves together in the most peculiar formations and so long as their surfaces look married it is wise to leave them alone. In cases where a short-circuit or other accident has caused blobbing, the file should only then be used to remove the blob ; it is not necessary to file away down until the valleys are removed also. Figure 3 illustrates pairs of partly-worn main contacts, where there is no need for dressing with the file.

AUXILIARY CONTACTS : THE "SUPPLE CONTACT"

In recent years efforts have been made to improve auxiliary or relay contacts with the two-fold objective of improving the lightness of action without introducing unreliability through dust, and of developing a contact which could be used in a wide variety of apparatus. The principal applications so far are for master switches, contactor interlocks and the contacts of calibrated relays.

For master switches, the principal objective has been to reduce the rate of contact wear. Maintenance engineers will know the extraordinary difference in

Fig. 4—Supple contact for control circuit (one side of bridge-piece removed)

rate of wear of the copper in conventional barrel-type masters between dry contacts and those having a smear of vaseline. It is difficult to ensure that the switches are inspected sufficiently often when they are in continual use and over-greasing must be avoided if reliable operation is to be obtained. Cam-operated controllers in the past have often been less easy to operate ; a reliable light contact was needed to ensure that the action of the switch should be as easy or if possible easier than the barrel type.

For contactor interlocks, the weakness of the usual construction employing an interlock bar engaging phosphor-bronze stationary fingers lies in the power required to operate them. To ensure operation which is free from dust trouble, the fingers require fairly sturdy springs. This imposes a two-fold limitation. One can only have a very limited number of interlocks per contactor and the operation of the contactor at low voltage is affected.

For sensitive relays calibrated for voltage, current, or frequency, the problem is essentially one of retaining reliable contact operation whilst reducing the power and thus increasing the sensitivity of the relay.

Continuous experiment to discover an improved contact for use in the three principal categories mentioned above has produced one good solution—the " supple contact." This is illustrated in Fig. 4. It is mounted with its contact surfaces vertical so as to avoid the collection of dust. The supple contact is the moving element which bridges two fixed contacts which, of course, are of rigid construction and fitted with silver faces. The bridge-piece of the moving contact is in itself solid but is surrounded by a connecting strip of springy phosphor bronze which carries the two silver buttons for engagement with the fixed contacts. The amount of spring provided by the connecting strip is small and the angular movement with which the contact button is thus endowed is very small indeed, but it makes all the difference between a plain strike and a wiping action when the contact operates. The whole bridge assembly can rock for self-alignment on the two posts, but it is the minute angular movement of the buttons which provides freedom from dust troubles.

Failures to make contact with the " supple contact " amount to only one or two per million operations.

SECTION II—DUST AND ENCLOSURES

The pursuit of dust-tight enclosures for individual control panels is often a false ideal. The continuous breaking of electrical circuits ionizes the atmosphere and in a hermetically sealed enclosure it is surprising how soon the degree of ionization becomes sufficient to cause a flash-over to earth between live parts and the contactor cubicle. If, therefore, the enclosures are sealed against the external atmosphere an efficient system of pipe ventilation with filtered inlet may be necessary, a complication which is seldom adopted.

Cases have occurred of hard-working apparatus which apparently continues to function to the satisfaction of its owners when covered in dust to the angle of repose. Occasional failures in such circumstances have enabled the details to be modified so that dust has ceased to be regarded as a serious menace. An example of such a change in detailed design is given by the insulating tie-bar which connects pairs of reversing contactors. This was originally of square section, with the upper side almost horizontal. In spite of the continual movement of the contactors sufficient dust accumulated on this surface to give occasional trouble on 500 V. circuits by a burn across opposite poles. Most of the length of the tie-bar was machined until it had a pronounced apex in cross-section (as shown in Fig. 5), with successful results.

In steelworks, since it is unusual to encounter dust and dampness at the same time, clogging is not a general tendency which would render the exclusion of dust essential. Open-type contactor gear may, if necessary, be installed in situations where the atmosphere is heavily charged with dust, provided that there are facilities for the maintenance staff to use a blower. Experience shows that in connection with auxiliary contacts, much dust is not a great deal more troublesome than a very little dust in producing the occasional non-circuit which is exasperating to the operatives when working against time.

Seeing that no practical form of enclosure will exclude all the dust all the time, it can be understood how in steelworks practice the emphasis has been laid, first of all on producing reliability in spite of the dust and, only as a secondary consideration, on the exclusion of the worst of the dust by using ventilated enclosed panels.

When new layouts are under consideration for steel plant, it is wise and convenient to provide special buildings for contactor gear so that the latter may be of the open type and yet remain clean. The ease

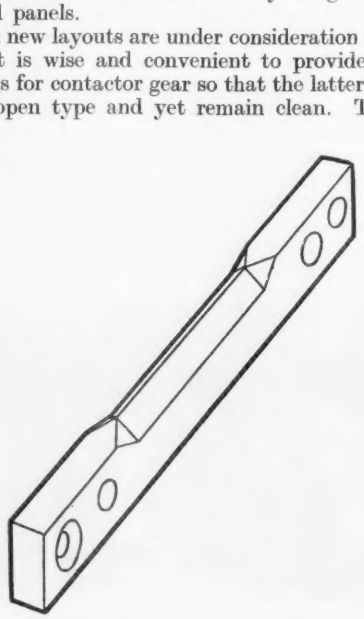

Fig. 5—Tie-bar for D.C. reversing contactors

of inspection and freedom of movement thus given encourage good maintenance. Figure 6 shows the open-type construction of a group of contactor panels for steel-mill auxiliaries. Two switchboards are braced together in a back-to-back factory-assembled construction having the resistances mounted above the cross-bracing with a cat-walk in between. Figure 7 shows part of a group of enclosed ventilated contactor cubicles ganged together to form a unit containing the apparatus necessary to control one large A.C. motor in a rubber mill. Similar construction is used for steel-mill auxiliary motors, each being housed in one section of the switchboard with a system of bus-bars running the entire length and possibly a circuit-breaker cubicle at the end. Each door is provided with a tear-drop handle and is arranged to hinge either right- or left-handed, according to requirements. Each handle operates bolts at top, centre, and bottom of the door. Where necessary the door operating gear is mechanically interlocked with the isolating switch.

On cranes the tendency towards more contactor panels and fewer manual controllers is also encouraging the use of open panels mounted in contactor houses. In the days when only the main hoist was deemed worthy of the expense of automatic gear, the argument in favour of a contactor house was insufficient. If all or most of the motions have this type of control it can be shown that the over-all cost is approximately equal whether the apparatus is housed in individual enclosures or in an all-embracing sheeted-in portion of the structure.

It is always harder to ensure good maintenance on overhead cranes than on floor plant, so that the growing popularity of contactor houses is welcomed by control manufacturer and user alike. For some crane builders it may as yet be a moot point, but the author feels that experience in the design of such plant will show that the space required is no greater, though the emphasis should really be placed on the more efficient use of the space available and the great increase in safety during maintenance. The space is certainly less when the two types of installation are compared, each being equally safe and equally accessible.

Individual enclosures for crane panels will find application for many years to come ; the problem of doors on the larger units is, as yet, without a satisfactory solution. One large door gives good access, but cannot be hinged for lack of room. Lift-off doors are always preferred, but their size may be unwieldy. On overhead cranes it is important for the panels to be disposed so that the door is not removed whilst the attendant is standing with his back to the drop between the girders. With two doors the centre bar interferes with maintenance : with four doors the obstruction by the cross-bars is worse. Moreover, it is valuable to construct the enclosure so that the cross-bar(s) can be removed easily.

Observation is the secret of good maintenance, therefore open control boards should be installed wherever possible.

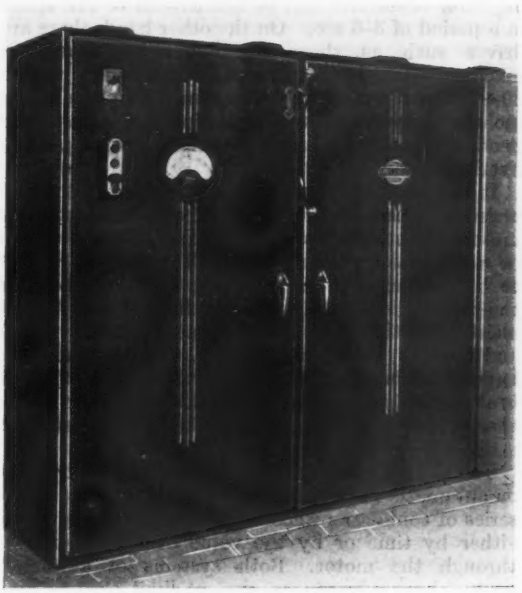

Fig. 7—Enclosed cubicles ganged together with hinged doors

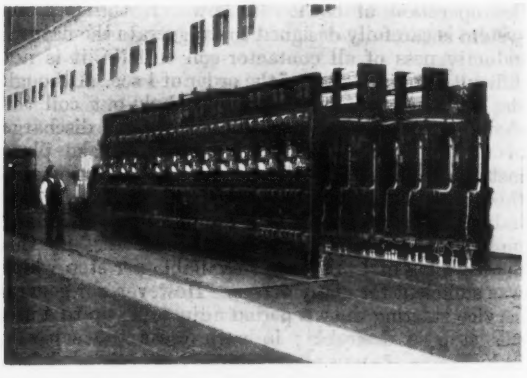

Fig. 6—Open-type back-to-back contactor panels for mill auxiliaries

SECTION III—METHODS OF CONTROLLING THE ACCELERATION OF MOTORS

CHARACTERISTICS OF MACHINERY WHICH AFFECT ACCELERATION

The information of most importance to the control-gear designer is the nature of the driven mechanical load. This in turn depends upon the relative importance of the work done by the machine and the work stored up in its moving parts during the starting-up period. There is always a certain amount of energy stored in the flywheel effect of the motor alone and brake pulley if such exists. This leads to the useful conception of assessing the stored energy of the connected machine in terms of fractions or multiples of one motor armature. A very large proportion of machinery driven by electric motors has a low relative inertia varying from a fraction up to two armatures. As most motors in the usual sizes and speeds, *i.e.*, not exceeding 50 h.p. and 1500 r.p.m., will start themselves in less than one second, under the influence of full load torque it is found that a total inertia not exceed-

ing three armatures can be accelerated to full speed in a period of 3–6 sec. On the other hand, there are drives such as those for hydro-extractors and machinery fitted with flywheels which may require 30–90 sec. for starting up; examples in steelworks include flywheel shears, guillotines, cropping, and bending machinery and the longitudinal travel of overhead cranes.

It can be seen, therefore, that the rate at which resistances can be cut out of circuit when starting motors depends on the inertia and not on the output or work done by the machine. The amount of heat to be dissipated in the resistances is quite small if the inertia is small, and the physical size of the resistances, therefore, is also small. With flywheels and the like, on the other hand, the resistances are large and it is approximately correct to state that the heat to be dissipated is the thermal equivalent of the energy stored in the moving parts when operating at rated speed.

The resistances are cut out of circuit either by hand or automatic means, the latter usually comprising a series of contactors whose rate of closure is governed either by time or by the value of current flowing through the motor. Both systems of automatic control have advantages, current limit or time limit being selected by the designer in accordance with the requirements of the load which the motor will drive.

CURRENT-LIMIT DEVICES

The Series Relay—The coil is energized by the motor current. The contacts are in series with the pull-in coil of the contactor which the relay controls, and the relay is set by means of an adjustable spring tension. When the current is no longer sufficient to hold the contacts open, the spring succeeds in closing them, the contactor operates and the step of resistance is cut out.

The Series-Wound Lock-Out Contactor—This has a restraining coil acting on the armature on the opposite side of the fulcrum or pivot pin. In its inactive condition, the contactor rests by gravity with the air gap of the restraining or lock-out coil nearly closed and, as the contactor closes, this air gap is extended whilst that of the pull-in coil is reduced to nearly zero in the usual manner. Since the pull-in air gap is reduced as the contactor closes the power of closure is built up rapidly and the provision of a lock-out tail does not, therefore, impede in any way the quickness of action of the contactor. The lock-out in fact provides a trigger action, and this type of contactor is fractionally more positive than ordinary contactors which are otherwise of the same electrical design. The lock-out air gap is adjustable so that the contactor may be set to operate at a suitable value of motor current.

The Shunt-Wound or Voltage Lock-Out Contactor—The mechanical construction of a modern type can be seen in Fig. 2. The hold-out coil, instead of being energized by the series current through the motor, is tapped across a portion of the starting resistance. The advantage of voltage compared with current lock-out lies in the easier manufacture, and the fact that the same panel is suitable for all sizes of motor within its capacity.

The Counter E.M.F. Starter—The resistance contactor is energized by the rising voltage across the motor brushes which in turn varies as the motor speed and inversely as the motor current.

An interesting current-limit control is obtained by the use of a clockwork train terminating in an eddy drag disc which operates in a flux provided by a series-responsive coil. Usually this is a multi-contact relay operating gradually to cut in the required number of accelerating contactors. Sometimes it is not a relay at all but has contact fingers of sufficient capacity to handle the main current direct. Furthermore, the disc can be restrained by a shunt as well as a series field so that any combination of time and current control can be obtained.

TIME-LIMIT DEVICES

The Mechanical Vane Timer—One type comprises a multi-finger relay restrained by a clockwork train similar to the preceding eddy drag unit but terminating in an air vane. Another type is a similar but smaller mechanism with a single contact. It is actuated by one contactor and the relay contact restrains the contactor next in sequence.

The Clock Timer—This is similar in construction but is fitted with an escapement to provide the control instead of the air vane.

The Eddy Drag—This is employed with shunt excitation only.

The Oil Dash-Pot and Mercury Dash-Pot

The Pneumatic Diaphragm Timer—This simple mechanism is probably the most successful of all cheap types. The diaphragm is of elastic fabric and is used to seal a small air chamber with adjustable leak valve. Each timer has a single set of contacts, is actuated by one contactor, and restrains the next contactor in sequence. Instantaneous resetting is provided by a simple non-return valve.

The Inductive Time Lag (I.T.L.) and the Condenser Time Lag (CondITLe)—Returning to the voltage lock-out contactor shown in Fig. 2, suppose that the step of resistance used for energizing the holding coil is short circuited by the preceding contactor, it would seem that the contactor controlled by the hold-out would close immediately, and that such an arrangement would retain the contactors in their correct sequence but without perceptible time lag between the operation of each. If, however, the lock-out system is carefully designed to exaggerate the natural inductiveness of all contactor-coil circuits, it is not difficult to obtain a lag of the order of 1 sec. Although the voltage is removed from the hold-out coil the short circuit also provides a path for the discharge of the coil current and this does not take place instantaneously. On the earlier I.T.L. equipments the time lag was boosted by the provision of additional inductance in the form of a number of coils banked on a common high-permeability iron core. By this means a lag of 1–2 sec. was available per step which was sufficient for many drives. However, for general service starting duty a period adjustable up to 4 sec. per step is desirable; in such cases the separate inductances are now replaced by a reservoir condenser in parallel with each hold-out coil. It is then necessary to energize the hold-outs off the line voltage and

to disconnect each by a pair of normally closed interlocks on the preceding contactor. The latter system is referred to as condenser time limit or CondITLe control.

The separate inductance bank is unnecessary for the standard contactor panels which control racks, skids, pull-across, screwdown and manipulators, as the starting period required is very brief.

SECTION IV—APPLICATION OF TIME- AND CURRENT-LIMIT SYSTEMS

STARTING

Current-limit control is still universally used for drives having a very high inertia such as hydro-extractors. It is usually adopted also for medium inertia equipments such as flywheel shears although sometimes even here there are good reasons for advocating a time-limit control. Adequate time can be provided with CondITLe control having two or three instead of the usual one 25 μF. condenser per step. For general industrial starter duty, time-limit control is the standard method.

For mill-auxiliary duty it was formerly postulated that current-limit control was correct. Series relays or lock-out contactors are simple and can operate millions of times without wearing out. The drawbacks, however, are three-fold. Firstly, the motor is accelerated at an unnecessarily violent rate if the machinery turns out to be over-motored or if it operates often under light load conditions. Secondly, the settings are easily wangled in emergency and then not usually restored. Finally, the principal objection lies in an incorrect interpretation of what a mill-type motor has to do. It should start with normal current whenever it can and thus be kept cool, but it should not be prevented from developing its rated 3 or 4 times full-load torque when the state of the machinery makes this necessary. If a current-limit system is set to release successive contactors when the current has waned to a value slightly over full load, that will ensure that the motor can drive any load not requiring more than full-load torque, but the motor will start too quickly on dead-light load. If the load is higher than full-load torque, the current cannot drop to the relay settings, the contactors remain locked out, and the drive cannot start. If higher settings are adopted, the risk of stalling is decreased ; but in mill practice the target is to permit 3 to 4 times full-load torque to be accelerated and, clearly, relays set for such values will be quite unsuitable for a reasonable start under normal conditions.

If a time-limit control is adopted, a 1-sec. lag per step causes no noticeable hold-up in starting and is ample for most drives to allow the motor to accelerate smoothly and without excess current. A failure to start with the normal current is quickly taken up by the closure of successive contactors and the motor can develop adequate torque for any reasonable condition or even emergency. If the motor remains stalled, the overload relays will disconnect it almost instantaneously when the current has reached 300 or 400% towards the end of the time provided by the I.T.L. equipment. It should be noted in this connection that the total time is extended somewhat by excessive load.

PLUGGING

It is convenient and accepted practice, in steelworks particularly, to stop quickly by reversing the motor at speed, an operation known as " plugging." This can be done without harm to motor or machinery providing sufficient resistance is retained in series with the motor from the time it is plugged until it is nearly at rest and therefore ready for a normal start in the other direction.

On mill equipments, a single additional step of resistance is used for this purpose. The total resistance is then such that 65% of the full-load current is passed on the first step of the controller with the motor at rest, which is a very suitable value for inching and light torque movement. The problem is to find a means of locking out the shorting contactor automatically while the motor is running backwards and yet to provide for instantaneous closure of this contactor when it is desired to make a quick start from rest. Plain voltage lock-out control fulfils this function completely. The motor cannot continue to run backwards indefinitely as, except on hoisting machinery or unlevel traction, the load cannot drive the motor. With reverse current applied, therefore, the motor will in fact stop quickly. Consequently, if a voltage or current lock-out is adopted to control the plugging step only, and is correctly set in the first instance, it does not suffer from the weakness inherent in such a method if used to control the accelerating contactors.

It is essential that the plugging contactor should close before the motor reaches standstill. If necessary the setting of the contactor should be checked by deliberately stalling the machinery. This should be done if possible under the most adverse conditions of drooping supply voltage, and when the contactor coils are hot, *i.e.*, when the pull-in coils will be operating at their weakest.

PLUGGING : CRANE LONG TRAVEL

Principal reference has so far been made to the floor machinery fixed drives of mill auxiliaries. A special case of the application of I.T.L. should now be considered, namely, the long-travel drives of cranes. Here there are two main differences. The machinery has considerable inertia and the drive is not positive, inasmuch as it depends upon the adhesion between road wheels and rails. A much larger starting-up period is usually required so that the CondITLe method of controlling the accelerating contactors is employed. Also, special care must be taken in designing the plugging circuits. Provided that a sufficient but smaller-than-usual current is allowed to pass when the motor is reversed at speed, the crane can be stopped smoothly and efficiently by plugging. However, it is then obvious by test that with D.C. drives a current which is suitable at full-speed reverse wanes to an inadequate value by the time the crane is down to half-speed. One therefore requires two plugging contactors, one permitted to close at half speed and so to maintain the braking of the crane, and the second to hold out until the crane is almost at rest. When two contactors are thus used, the crane can be stopped by plugging with a smooth and adequately maintained retarding torque.

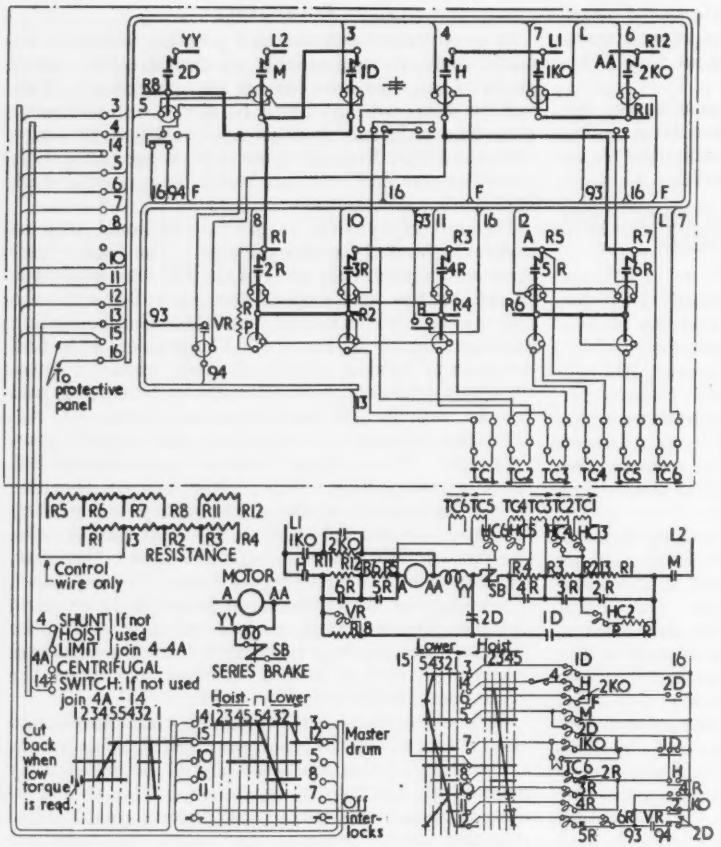

Fig. 8—Diagram for crane hoist showing I.T.L. control and hook-up for inductance; overload and no-volt protection separate

As in the travelling motions of overhead cranes half of the wheels are driven, the question of wheel slip seldom becomes a serious problem. The high acceleration required for charging machines on the one hand and the occasional misbehaviour of wide overheads (say in excess of 80 ft. span) on the other hand, make it advisable to drive all the wheels of these machines. The difficulty with wide-span cranes may be due to their lack of rigidity : with medium-span and particularly with very narrow cranes, the adhesion seems to vary inversely with the span, reaching surprisingly high values in the very narrow ones.

DIAGRAM OF A TYPICAL CONTROL SYSTEM

Figure 8 shows the panel layout and connections for an I.T.L. dynamic-lowering hoist equipment. In the key diagram (towards the bottom and at the right-hand side of the Figure) the coils of the inductance bank are marked TC1 to TC6. It will be noted that the polarity of the coils alternate in sequence, with the exception of TC4. TC1 is energized off the first resistance step by taps at R13 and R2 and has the holding coil of contactor 3R in series with it ; TC2 is in series with HC4 across R2–R3 and so on. TC4 with HC5 is energized solely by the flux from the core of the inductance. TC6 is energized only during lowering, from the master switch finger 7. The circuits are interlocked so that in hoisting, the main current is passing and the inductance coils are energized before the pull-in coils of the resistance contactors. In the event of switching full on to hoisting from rest, the first of the latter, 2R, closes almost instantaneously and short circuits R1–R2 along with coils TC1 and HC3. The flux in the inductance reverses and sustains a holding current on the tail of 3R contactor, which closes after this inductive lag. 3R short circuits TC2 and HC4, enabling 4R to close after a further lag and so on.

Proceeding from rest to the first step lower, the pull-in coils of all the resistance contactors are energized before the inductance and close almost instantaneously, thus establishing the slowest speed without delay and preventing the load from running down except at minimum speed. The principal functions of the main circuits are discussed in the sub-section on potentiometer lowering and dynamic braking for hoists.

It will be seen that the panel comprises main circuit and resistance contactors only, the overload and no-volt protection being provided by a separate crane-protective panel.

STARTING AND PLUGGING OF CRANE CROSS-TRAVERSE : NUMBER OF CONTACTORS

The cross-traverse drive presents another interesting problem with features parallel to those of the long-travel. The usual four-wheel bogie is much lighter when there is no load on the crane than with full load, but in selecting the size of the motor adequate power must be provided for satisfactory operation when the motion is used at full capacity. We can say more concisely, when comparing the two drives, that the unladen/laden weight ratio for cross-traverse is usually much smaller than for long-travel, though this difference is not so pronounced on man-trolley jobs such as soaking-pit cranes and chargers. Consequently, the probability of wheel-slip is much greater for cross-traverse drives. If it were not for some mitigating factors one would naturally assume that three plugging contactors would be necessary if two are correct practice for the long-travel ; the extra contactor would not necessarily be controlled by an automatic hold-out device, but would be at the driver's discretion so that additional resistance to avoid skidding the wheels would be available when the

trolley is unloaded; this refinement has not been found necessary in practice. It is, however, possible that cases will occur when some of the mitigating factors are absent or suppressed; these appear to be:

(i) Square and rigid wheel plan. This seems to produce high adhesion.

(ii) Short maximum movement. This limits the motor speed and consequently the maximum current when plugging takes place.

(iii) Relatively low geared speed. This has several influences. In the first place, the inertia duty of the motor is lower in relation to its friction duty, which limits the free speed. In the second place, the loss of torque as the motor slows down is not obvious, as the friction, except on trolleys fitted with roller-bearing axles, is effective in maintaining the deceleration. In the third place, the total time required for a smooth and efficient stop is so short that a loss of torque would not be important. In the fourth place, the short plugging time has a material effect in rounding the current peak and so in reducing the maximum torque at the moment of plugging—a benefit which is derived from the inductance of the motor, but which is only available when inertia is low.

If it were practicable to analyse each cross-traverse drive as it occurs, it would be found that many of them could be provided with adequate control if the panel had only one plugging contactor and two accelerators, a total of three resistance contactors in all. An optional permanent step of resistance of low value can be left in circuit. However, there is a considerable variation in design and motoring which makes it advisable, and certainly more simple, to use four contactors and rather more resistance. If these are arranged one for plugging under current or voltage lock-out control, and the remainder for accelerating by time control, it will be found that a smooth reversal or plug stop is available, but that in starting from rest with full load there is a slight delay. The plugging contactor will have closed instantaneously, but there is insufficient current to move the trolley until the first accelerating contactor has closed. As the time per contactor for the low-speed cross-traverse drive is quite short this pause in practice is not sufficient to cause annoyance. With the trolley lightly loaded, of course, movement will commence instantaneously with the application of power.

If, instead of the above arrangement, two contactors are designated for plugging duty as on the long-travel drive, and two for acceleration, the delay on starting with load is eliminated but in unfavourable circumstances wheel-slip may occur if the driver applies full power when starting the unloaded trolley.

Owing to the need to use the panel area efficiently, the number of contactors should be even. There are five line contactors, one main, and four reversers; it is, therefore, usual to adopt three or alternatively five resistance contactors, making a total of eight or ten which can be disposed in two rows of four or five. For standardizing a cross-traverse control which will be efficient in all applications, it has been shown that four resistance contactors are desirable; it is, therefore, obvious that one might as well adopt five, the last contactor being used to cut out the permanent resistance step of low value already mentioned. The number of contactors and physical layout of the panel would then be similar to that used for long-travel duty. If, therefore, the resistance contactors are arranged two for plugging and three for acceleration (instead of one and four) it is possible to use control panels for cross-traverse which are identical to long-travel not only as to diagram but in every other detail of design.

PLUGGING OF UNLEVEL TRACTION

In the foregoing remarks it has been assumed that the track is level. However, with outdoor plant, such as transfer cars for blast-furnaces, gradients may be encountered. In such cases it is advisable to check the operation of the plugging contactors when stopping the car from full speed down hill. It is probable that the initial settings will have been made on the level and the purpose of the check is to ensure that sufficient braking power is permitted to the driver by the automatic control to allow him to stop anywhere with reasonable promptness. Such equipment is usually provided with pneumatic brakes so that the driver is independent of the electric control, but nevertheless it is better to arrange the contactor settings so that the down-hill stop is also satisfactory by means of the motors. The tests should be made under full load.

PLUGGING OF CRANE HOIST

The influence of a slight overhauling load on the setting of plugging contactors appeared in the above. If a crane hoist is carrying full load and is being lowered at full speed, the extreme case of this influence is reached when the master switch is reversed. Such treatment of the control should be discouraged as it is in most cases quite unnecessary (see end of subsection on dynamic braking for series motors for hoists). Nevertheless, it must be expected that the driver will plug occasionally. There is one type of incident when one could not blame him for doing so. If, owing to some mistaken signal or other surprise, the descending load is found to be in danger of injuring floor personnel or causing damage, the reaction of nine people out of ten will be to plug the control. It is therefore necessary, when putting new control gear into commission or checking the performance of an existing installation, to test its performance under this condition.

If the equipment is provided with a current-limit control or its equivalent for the plugging contactor(s), it is possible that insufficient current is passed to cause the load to come to rest. Evidently the amount of current required depends upon the load, so the setting should be carried out with full load or test load on the crane. Unless the control-gear is wrongly designed or out of order, or unless the resistances are incorrect, there will be ample current passed to decelerate from full speed in lowering, but attention should be given to the possibility that the closure of the plugging contactor is prevented. This may occur because after initial retardation an equilibrium is reached at perhaps half-speed when steady lowering continues, the current then being stabilized at a value which is only sufficient to sustain the overhauling torque provided by the load. The supervisory control of the plugging contactor must be adjusted so that it is permitted to close somewhat before this condition

is reached; continued retardation to standstill and reverse is necessary.

SECTION V—THE CHOICE OF FIELD WINDINGS FOR MILL-AUXILIARY MOTORS

ADVANTAGE OF SERIES MOTORS (COMPARED WITH SHUNT) IN REDUCING CURRENT PEAKS AND NUMBER OF RESISTANCE CONTACTORS

The reasons for preferring the series motor for traction and in steelworks are well known, but some features are of particular interest to the manufacturer and user of control gear.

Field-Forcing

When a step of resistance is short-circuited the increased current through the motor forces the field. The flux and therefore the counter-e.m.f. are thus also increased, an effect which is absent from the shunt motor. The result is that a smaller number of accelerating contactors is required, given that the basis of comparison is the limitation of the current to the same maximum value.

Inductance

Owing to the field winding forming part of the main circuit the series motor has a greater inductance than a shunt motor and in consequence the current does not attain its peak value so readily when a step of starting resistance is short-circuited. A series-wound brake adds to this effect, and may only be used with a series motor.

Suppose the driven machine, which is being accelerated by the motor, has a very large inertia, the increase of current caused by the closing of a contactor which cuts out a step of resistance will not quickly produce an increase in speed. The inductive effect of the motor will delay the attainment of peak current for perhaps a half-second, but as the machine requires several seconds to accelerate the speed has not changed appreciably by the time the inductive effect has faded out. The inductance of the motor cannot then produce any benefit in preventing the current from attaining the same maximum as would occur if the motor had no inductance. If the inertia is low, on the other hand, the machine will be accelerating as the current grows. As the machine and motor accelerate, the latter develops more counter-voltage in its armature, and the counter-voltage prevents the current from attaining so great a value as would occur if the speed of the motor had remained virtually unchanged.

Many steel-mill-auxiliary drives have a low inertia, notably screwdowns and crane hoists. The former, with series motor and suitable resistor design, can be started up by means of one accelerating contactor only, another being required for limiting the current on plugging. Three resistance contactors are, however, usually adopted as this gives better inching control. A crane hoist requires from four to six resistance contactors owing to the variation of load and range of speed control required, particularly during dynamic lowering.

Three resistance contactors are standard practice for the general run of auxiliary drives, including skids, roller tables, manipulators, and so forth.

A Special Example

Some while ago it was decided to drive breast rollers by means of direct-coupled compound-wound mill motors. Two sizes of motor were used rated for 16 and 28·6 h.p. at 100 r.p.m., with uncoupled running speed limited to 220%; the frames used would have an output of 100 and 150 h.p., respectively, when wound for a normal speed. A standard I.T.L. control panel was supplied having three resistance contactors and four resistance sections. The last step of resistance was left permanently in circuit so that the motor would stall at twice full-load current. As the internal resistance was 30% this external permanent section was only 20%. The 16 h.p. drive, which was the first in service, was tested for inductance/inertia behaviour, and gradually all the resistance was cut out except for the stalling section. It was possible to plug the drive at full speed (120%) without damage, only a slight and harmless spark being noticeable at the brushes. Had it been a series motor, it probably would have plugged without resistance at all, possibly with no sparking.

The torque of the 16 h.p. motor at 100 r.p.m. is approximately the same as 97½ h.p. at 515 r.p.m. If the frame, wound for the latter rating, had been geared down 5·2 to 1 to the breast rollers, the armature would have been able to reverse the rollers say, five times more easily. On the other hand the moment of inertia of the armature has remained unaltered, and as its speed is five times greater the stored energy to be dealt with becomes twenty-five times greater to which must be added the energy in the gearing. The time constant of the motor remains virtually unaltered by the fact that a different winding has been employed, so that the main significance in the use of the slower-speed motor of smaller horse-power lies in the reduction in power to be controlled, the saving in consumption if safe stalling is to be permitted, and the great improvement of design and reduction of maintenance effected by omitting the gear. The time constant is the same in the case of both motors because it is determined by the ratio of the inductance to the resistance, and both of these are increased to approximately the same degree by winding the frame for a special low speed and reduced horse-power. To what extent the omission of the gear and the use of a slow-speed frame will improve the inductance/inertia behaviour of the drive depends upon the relative values of the moments of the armature and of the rollers, respectively.

Returning to the question of current peaks, a 16 or perhaps 20 h.p. motor of normal speed might have been used to drive the rollers through a gear. The time constant would have been much smaller and direct-switching would certainly have been impossible. It should now be clear that the inductance which limits the peak current is inherent in the frame size of a machine independent of its type of winding, and that the use of the large slow-speed motor mentioned above enables the advantages indicated to be obtained.

AVOIDING OVER-SPEED WITH SERIES MOTORS

If the series characteristic is not desirable there is surely no reason why the speed/torque curve should not be flat and, if this be granted, a shunt motor

should be used. In cases where the series characteristic is an asset but over-speed is feared, a light permanent armature diverter resistance can usually be installed either initially or as a result of experience after the drive has been in service. In some cases a centrifugal or electrical over-speed switch can be used instead.

From experience in the behaviour of steel-mill auxiliaries, it seems that series motors should be used where possible and that shunt motors should only be used as an alternative where necessary. In this connection the term shunt would include compound motors where the series winding is relatively small and would exclude those in which the two windings are more or less equal. The latter will, for brevity, be termed 50/50 motors. It is assumed also that the motors are required to start, stop, and reverse, frequently and with minimum delay.

FIELD WINDINGS FOR CRANES

Discussions still occur from time to time as to the need for shunt-limiting windings on crane hoists; damage to armatures through over-speed will only take place if plain series control is used in the lowering direction. Load-brakes have fallen into disfavour owing to the many unsatisfactory designs which have been supplied. Good designs have given excellent service over long periods in many instances, but the others are usually removed or circumvented in such a way that there is a large number of hoists now in operation with plain series lowering and no effective load-brake. These may account for the persistence of the idea that a series motor should not be used for hoists.

Further, in spite of the universal popularity now of the dynamic-lowering hoist control for series motors, the allegation is sometimes made that lowering by this method is too slow. I.T.L. (inductive time limit) control is in widespread use for steady-state lowering at 200% of rated full-load hoisting speed with both industrial and mill-type motors, this speed being attained for both light hook and full load. There are also many dipping or quenching cranes which lower full load safely, and with perfect commutation during rapid switching, at speeds in excess of 250%. The motors are all standard series-wound machines. The I.T.L. control is designed so that, when speed is reduced after lowering at these high values, the load is retarded by a series of time-graduated steps which protect the motor against excessive current and yet rapidly commutate the resistances in order to maintain a high value of retarding torque as the speed is reduced. If drum controllers are used for this class of work, with the smaller motors, excessive currents damage both motor and controller every time the equipment is switched off rapidly. Consequently manufacturers are conservative in their lowering speeds for dynamic lowering drums.

The possibility of the series motor running too fast in the hoisting direction can, of course, only arise with an empty hook; cases where the armature has been damaged on this account are very rare. The torque and therefore the acceleration of the motor wane rapidly after the rated speed is passed, the

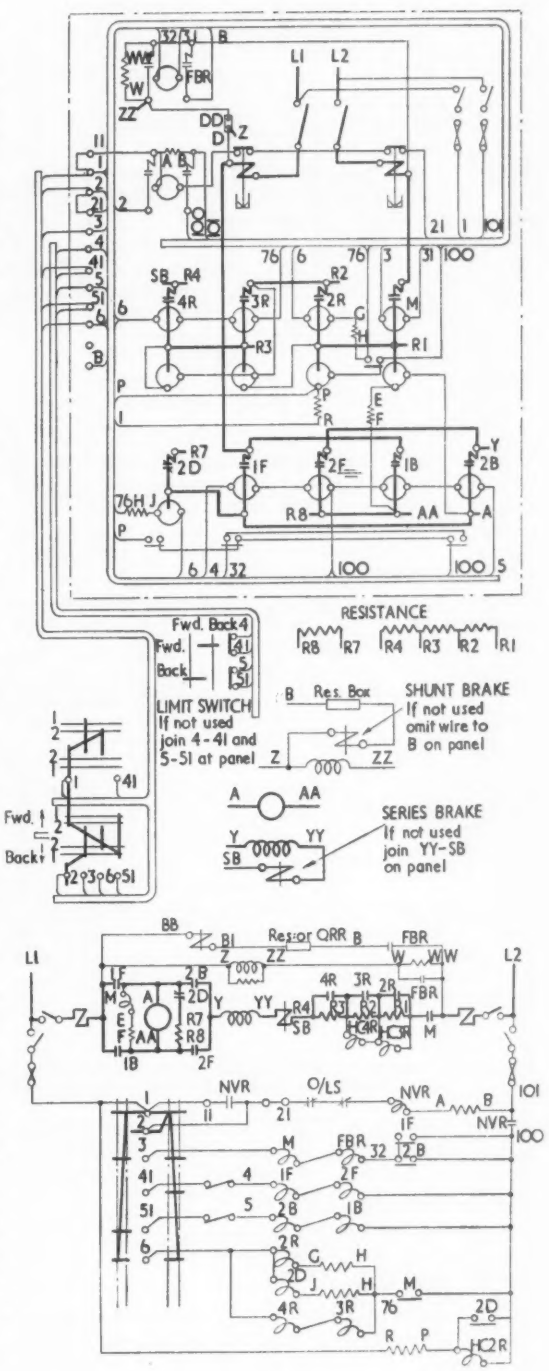

Fig. 9—Diagram for mill control panel; dynamic braking, non plugging; isolators, overload and no-volt protection included

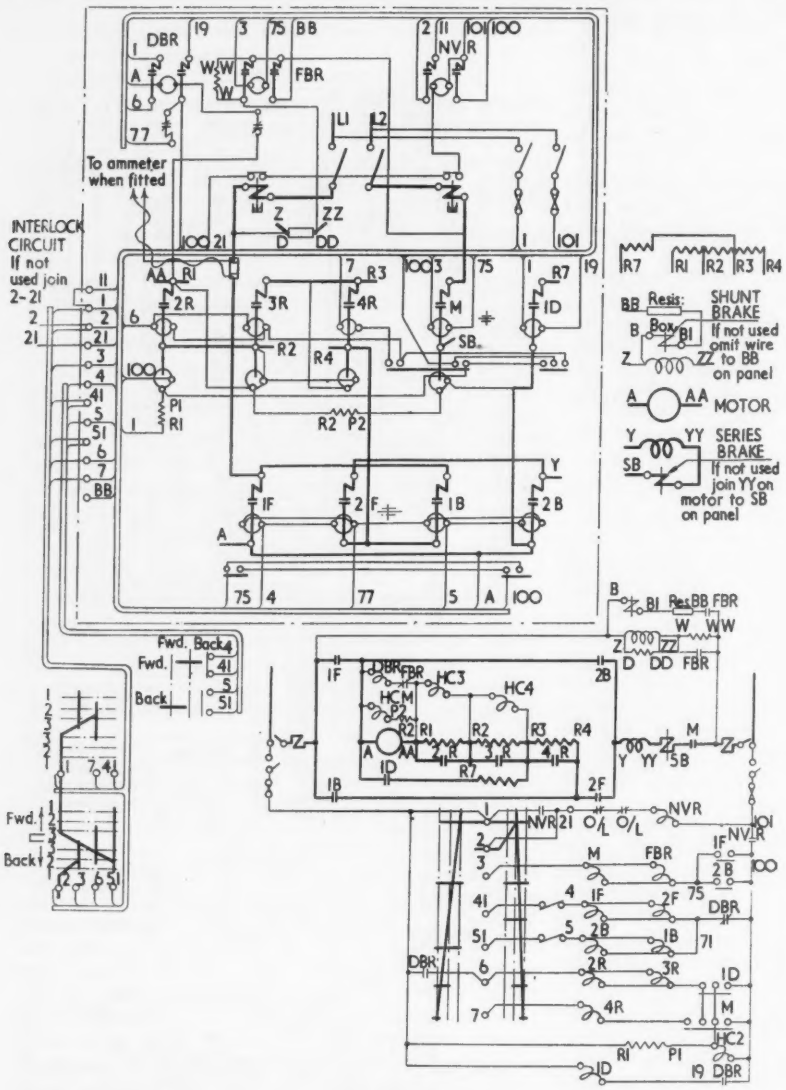

Fig. 10—Diagram for mill control panel; graduated dynamic braking, non plugging; isolators, overload and no-volt protection included

former being under 20% at 200% speed ; there is, therefore, seldom enough time available for a dangerous speed to be attained. The four factors which accentuate the risk are :

(i) A large hoisting distance.
(ii) A low (rated) hoisting speed.
(iii) A very light block.
(iv) Low friction.

It is seldom that these form a dangerous combination but where this occurs an over-speed switch should be installed. In connection with item (iv) the effect of using roller bearings and machine-cut gears is largely offset by the modern trend towards total enclosure in oil-tight gear cases, in which the viscosity of the oil at high speed produces a considerable drag.

It is generally conceded that the need to handle the shunt field through collector gear on overhead cranes is a serious disadvantage ; the above remarks may help to remove remaining doubts as to the wisdom of using series motors on hoists.

On the long - travel drive the subject of overspeed has been treated in "Electric Traction for Cranes,"* and the argument against shunt-limiting windings follows the same general lines as given above.

On the cross-traverse drive control gear has occasionally been supplied for compound motors, but there are few people nowadays who would seriously argue in favour of the latter. Even on an ore-bridge where there is a considerable distance between the ends of the maximum run, there is no time in which to endanger the armature(s) as the geared (rated) speed is so high.

FIELD WINDINGS FOR FLOOR PLANT

Owing to the improvement of bearings and reduction of transmission losses certain mill-auxiliary drives run too fast with series motors, notably the working roller tables of plate mills. The motor size is governed by the frequency of reversal and the inertia and, although damage to the motor through excessive speed on a long pass is not to be expected, it is the variation in speed with length of pass which causes the mill operators to complain that they cannot get efficient control of the rolling process. Compound-wound motors are therefore in frequent use at the present time for various types of stationary plant. The motors then require a flat characteristic and the rise in speed with light load is usually unnecessary and frequently undesirable.

OBJECTIONS TO THE 50/50 MOTOR

These are summarized in the simple statement that motors in which the series and shunt fields are of an

* R. A. West : "Electric Traction for Cranes." London, 1945, Sir Isaac Pitman and Sons.

equal order can be neither started nor stopped as quickly as series motors or shunt motors.

Difficulty in Obtaining a Quick Start

There is a powerful mutual inductance between the two fields the effect of which is unfavourable. The sudden increase of current in the series winding produces a counter-e.m.f. in the shunt which promptly reduces the shunt current and the resultant ampere turns from the shunt field are less than they ought to be; the shunt current may even be momentarily reversed. This is sometimes described as the "slugging" effect of the shunt field and can be improved, but not to any great extent, by locating the shunt winding on only two of the four poles. The series motor has the great advantage that its torque is improved by the field-forcing which takes place inherently during rapid acceleration; its torque per ampere is distinctly greater than with a 50/50 motor of equal frame size. When plugging the 50/50 motor for a rapid stop or reversal, conditions arise similar to starting and the shunt field "slugs" or spoils the effect of the series. Thus the series motor runs cooler and is more economical in power. In general a larger frame size must be adopted for the 50/50 motor to obtain equal performance.

Difficulty in Obtaining a Quick Stop

It is possible to provide dynamic braking on the control gear when the motor has a shunt winding. Figure 9 shows the diagram for a typical mill-duty reversing equipment which provides dynamic braking when the master is switched off, and an anti-plugging feature if the master is reversed. The line contactor M is in this case of the same construction as a normal I.T.L. accelerator and is provided with a hold-out coil which is connected across the armature. M drops out when the master switch passes through the off position and is then held out by armature volts until the motor is nearly at rest. When M is eventually released, its interlocks permit 2D, the dynamic brake contactor, to operate which in turn releases the accelerating contactors; 2R and 3R then close under I.T.L. control and the motor runs up in the reverse direction in the same manner as a normal start from rest. In this way plugging is prevented and the usual three accelerating contactors are reduced to two on this equipment, the plugging-resistance step and corresponding contactor being unnecessary.

It will be observed that during dynamic braking the series field is not energized. If this winding provides a fair proportion of the normal ampere-turns of the field, dynamic braking will take place under unfavourable conditions, that is with a weak field. It is possible to use the series field as well as the shunt for dynamic braking (*see* the sub-section on dynamic braking for plain reversing drives for series motors). The extra control gear needed is costly and too elaborate for mill panels, where simplicity is the essence of sound design. However, it should be noted that, even if both fields are used for dynamic braking, with the 50/50 motor the same interaction will occur as in starting from rest and the shunt will slug the series field.

The best conditions for dynamic braking are obtained with maximum field and a resistance in the armature loop which permits the maximum peak current consistent with good commutation. With the 50/50 motor the field is weaker than it ought to be, so the flux and hence the braking torque for a given armature current are reduced. Secondly, owing to the weak field, the dynamic current must be further reduced in order to secure satisfactory commutation. Dynamic braking for the 50/50 motor is, therefore, somewhat less effective than plugging, but neither method provides a really quick stop.

Furthermore, the less the value of the shunt in relation to the series field, the higher is the free-running speed on light load and the greater is the need for effective braking, but the less able is the motor to provide this with dynamic braking.

CHOICE OF DYNAMIC BRAKING OR PLUG BRAKING FOR THE SHUNT MOTOR

When the motor has a shunt field, therefore, it is recommended that the series field, if any, should be quite small, *i.e.*, that the speed/torque characteristic should be flat. As to the method of braking then to be adopted, either plugging or dynamic braking is available.

When plugging is used the torque would commence at about 150% at full speed reverse and would decrease to 75% at standstill. For dynamic braking the figures would be 150% down to zero. The speed/torque braking curve between the two points is in both cases approximately a straight line. If dynamic braking is used the average torque is lower and, if the machine has large inertia, low friction and no shoe-brake, there will be a tendency to drift at low speed. With dynamic braking there can be no reversal, but with plug braking it is evident that power must be removed when the motor comes to rest or the drive will probably reverse. Basically, dynamic braking is most suitable when the control is automatic, as in the case of a robot rod cooling bank in which a flag switch starts and a limit switch stops each cycle of movement. Plug braking is essentially a discretionary operation suitable for master-switch control. Nevertheless, dynamic braking may be designed for use at the driver's choice, and plug braking for automatic control, but the latter is on D.C. practically unused.

Referring to Fig. 9 it will be noted that the anti-plugging device operates every time the control is switched off. This can be a disadvantage for working roller tables, as the driver may switch off momentarily and then wish again to apply power. The anti-plugging device may be modified so that it will not interfere in this way, and yet retain an effective veto on any attempt to reverse the drive until the motor is nearly at rest. Normally in such cases plugging should be used instead, but there are two reasons why a user may prefer dynamic braking. The drive for a screw-down will have an electromechanical brake, and the fact that dynamic braking is automatically applied will considerably reduce the wear on the brake. Dynamic braking does not consume power and this second reason may also influence the choice.

Where coasting is required and the braking is to be optional, plugging is preferable. Where coasting

does not form part of the normal usage and if the control is automatic, dynamic braking should be used.

SECTION VI—GRADUATED BRAKING

CRANES

Reference has been made in a previous section to long-travel drives with series motors, in which two plugging contactors are used on account of the high inertia and the need to avoid excessive braking at high speed. Apart from the question of load swinging, the friction between wheels and rails sets a limit to the strength of braking which is desirable.

For a crane hoist, however, neither of these considerations is important and single-step braking is quite suitable from the mechanical angle. Graduated systems are nevertheless recommended for the reasons set forth in a later sub-section on dynamic braking for series motors for hoists.

FLOOR PLANT

For normal reversing duty on mill auxiliaries, the additional complication of graduating and intensifying the braking between full speed and zero is unnecessary. The connection diagram for an experimental equipment in which a special scheme of this type was adopted is shown in Fig. 10. The dynamic braking is automatic and takes place in three steps. The contactor 1D closes initially in the " off " position *via* contacts of the dynamic brake relay DBR, which is transiently energized from the armature voltage, and the braking resistance is R7-R3-R2-R1. Then the accelerators 2R and 3R close under I.T.L. control so that the final braking resistance is R7-R3 which can be of a low value owing to the graduation. An electromechanical brake B-B1 is shown in case it should be required, but this was an insurance policy, as the scheme was designed for a drive in which a brake was thought to be unnecessary and the dynamic braking was intensified with that object in view. A portion of the normal starting resistance R1-R2-R3 is used also for graduating the braking.

SECTION VII—LADLE TILTING CONTROL

Example of the Use of I.T.L. for Graduated Acceleration and Braking

Some years ago equipment was designed for the following requirements. Hot metal had to be poured from a ladle on to a pig-casting machine. The ladle was brought on a transfer car to the pouring position and remained on the car whilst a fixed hoisting mechanism, located on a structure over the pouring position, was used to tilt and return the ladle. Although the casting machine had a 3 to 1 speed range it was, nevertheless, necessary for the tilting to take place over a great range of speed and in smooth steps. The usual solution would have been a Ward-Leonard drive for the hoist, but the plant was not in continuous use and a direct control for a D.C. motor was evolved instead. As the rated speed was in any case quite low, the hoist motor being only 15 h.p., it was also desired to attain a high lowering speed and avoid blocking the railway for any longer than necessary. A shunt motor was used, having a speed increase of somewhat over 100% by field control.

The contactor gear was designed to give seven hoisting speeds of which the first five were diverter notches, the sixth retained a small series resistance only and the seventh operated the motor at full voltage and full field. On the lowering side the first notch placed the motor on full volts at base speed, whilst the second to the seventh notches weakened the field in a series of evenly graduated steps. The over-all speed range was 11 to 1 at all loads and could be somewhat greater if the shunt speed range and motor frame were also increased.

On the hoisting side, each successive notch cut out a step of series resistance and cut in a step of diverter. By this means a series of speed/torque curves was obtained which were practically parallel to each other and but little steeper than the inherent regulation of the motor when operating normally at full voltage. The resultant control of speed was for all practical purposes as good as could have been obtained by means of a Ward-Leonard set. Assuming that the field regulator of the Ward-Leonard generator is controlled manually, a bucking series field must be used in order to limit the main current to a safe value when the regulator is moved quickly. The effect of this field and the extra resistance of the generator armature produce a drooping speed/torque curve which is steeper than that of the direct motor control at full speed and no less steep at slow speed.

About a dozen forms of switching sequence were controlled by I.T.L. to prevent abuse of the motor, and the only automatic feature which was missing from this equipment was the full graduated dynamic braking in the " off " position of the controller. It would not have been difficult to incorporate this feature, but as the motor was small a weak dynamic current and an over-size electromechanical brake were considered adequate.

The supervision which is demanded from the contactor panel is considerably greater than that of the simple mill reversing equipment of the type illustrated in Fig. 9. It is, however, comparable with that provided in the modern dynamic lowering hoist.

SECTION VIII—WARD-LEONARD CONTROL

In the previous section reference was made to the use of a bucking series field on the generator of a Ward-Leonard set in order to obtain current stability when the controller is moved quickly. On a main mill drive where several thousand horse-power are used the time constant of the field is so long that opposite steps are necessary in order to persuade the field to respond more quickly, and some very interesting plant is used in order to obtain the desired response in both acceleration and deceleration.

However, in the region of 100–200 h.p. Ward-Leonard control is often used for crane hoists, particularly if accurate slow-speed control is desired. In such sizes it is not safe to switch on to full generator field from rest as the time constant is still too low and the field and generator volts can build up faster than the motor can accelerate. Furthermore, in switching off, the generator voltage collapses even more quickly and the armature current becomes excessive. The rate of change is highest at the beginning of the collapse, just when the speed of the

motor is at its maximum and the commutator least able to deal with the current. Consequently, it is common practice to provide a bucking series field on the generator even in this 100–200 h.p. range.

This arrangement suffers from the disadvantage that during the lowering of a major load the torque of the motor has to sustain the load and the current is therefore negative through both motor and generator. The series field of the latter is then no longer bucking but cumulative. If full load is being handled on the hook the current is about 64% of rated value (gear efficiency 0·8). Consequently, even with zero shunt field on the generator, the series field is considerable and it is impossible to obtain a good creeping speed in the lowering direction without placing the controller on one of the earlier hoisting notches, or having recourse to a foot brake. Such practice is bad and can be avoided quite easily if the generator is provided with only a plain shunt winding. The control gear should then operate the generator through a multi-notch master switch and a series of field contactors supervised by an inductive time-limit system. The latter can be set to increase and decrease the generator voltage at a rate which can be adjusted on site to suit the characteristics of the V–V set.

During service running the blast-furnace skip hoist is stopped automatically on limit switches. Accurate stopping is essential ; therefore the winch is retarded to a creeping speed by a series of slow-down limit switches before the final stop limit operates. An overhauling load occurs when a loaded skip has to be returned to the pit. The creeping speed will be much higher than normal if a bucking field is used on the V–V set, and an over-run will take place which may well be sufficient to place the top skip in " unfortunate circumstances." A shunt-wound generator should, therefore, be used in this application also, with supervision of field conditions by I.T.L. control.

SECTION IX—DIVERTER CONTROL FOR SERIES MOTORS

As a means of obtaining slow speed with light load the diverter is of common occurrence in most industries, generally in connection with series motors.

In brief it may be said that :

(i) Diverter control should be avoided rather than preferred.

(ii) When the plant is operated by a driver, diverter control is seldom necessary.

(iii) When the plant is controlled automatically, diverter control is required for accurate stopping.

For discretionary use (manual control) on equipment having a high inertia content, diverter control should be avoided when possible. A good example is the long-travel motion of a crane. The motor has a weak torque on the earlier points of plain series control, and this combined with the inertia results in a very slow change of speed. Experience shows that series control with coasting gives the driver all that can be desired in the way of slow speed. The steelworks hoist is a low-inertia drive, and in the lifting direction a diverter over one or two notches may occasionally be desirable for handling light machinery. Series control meets requirements for all loads in excess of 35%. It is feasible to introduce a simple diverter system, but care should be taken to see that the method adopted prevents the diverter from being applied at high speed. For the majority of hoists a divertor is unnecessary, and even for handling machinery a good driver can in most cases manage quite well without this feature. The most important requirement is accurate slow lowering, which is obtained with all good designs of dynamic and potentiometer equipment.

The ingot bogie and similar drives are often arranged for combined manual and automatic control. The latter is required for the operation of slow-down and stop limits at the end of travel. Providing there is a reasonable tolerance for the stopping position at the ends of the track, a straight-forward shunt-limit switch to cut off power may suffice, and the bogie will be arrested by the electromechanical brake alone. It may be necessary to stop accurately, either at the ends of track or in an intermediate position which cannot readily be observed by the driver, *e.g.*, at a discharging point. It is essential then to use slow-down limit switches so that the bogie may arrive at the final limit at a speed which will ensure an accurate stop, independent of the speed at which it entered the slow-down zone.

The introduction of series resistance by means of the slow-down limit switch is quite useless as the effect is widely variable according to friction load and speed ; further, this method cannot produce the negative torque which is required to pull down quickly the speed of a fast-running car. Diverter control is then the correct solution.

The ingot bogie will serve as a good example, as the inertia of a high-speed installation is considerable, the motor is usually of a size which has a rated torque of twice that required for steady running with the bogie carrying maximum burden, and the axles may be large in comparison with the diameter of the wheels. The requirements, therefore, are :

(i) The control must provide a considerable retarding torque when the bogie passes the slow-down limit switch, so that the slow speed may be attained quickly and time is not wasted between slow-down and final stop.

(ii) The slow speed under lightest load, that is with empty bogie and full lubrication, must be low enough to ensure an accurate stop.

(iii) The stalling torque must be so high that there is no risk of the bogie failing to reach the stopping position under the conditions of heaviest load, that is with maximum burden and poor lubrication: The

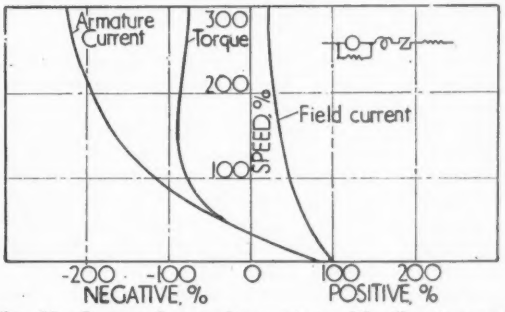

Fig. 11—Curves for series motor with diverter and series resistances

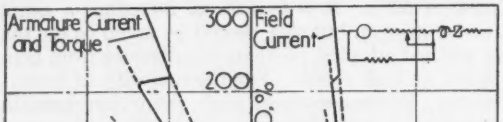

Fig. 12—Curves for series motor with diverter, series and armature resistances, and graduated slow-down

latter is a condition which is often overlooked, and occurs when the oil is cold and the bogie has been out of use. If the bogie should then stall, the resistances will burn out unless continuously rated.

Figure 11 shows a graph of torque, armature, and field currents against speed for the most common type of diverter control for a series motor. When the slow-down limit operates, the series resistance is inserted and a diverter is placed across the armature. The retarding torque is quite good ; the armature current is excessive at high speed ; the field current is low at high speed ; even the mill-type motor objects to such treatment, as the armature reaction is violent ; the light load speed is not really low enough ; the stalling torque may be inadequate. It is not usually recognized that the retarding torque reaches a maximum at a speed somewhat above rated speed, and then decreases again with still higher speeds. Any attempt to adjust the resistances encounters further difficulties. If the stalling torque has to be raised by reducing the series resistance the commutation at high speed is made even worse. If the slow speed has to be reduced, the consequent reduction in ohms of the diverter resistance not only increases the peak armature current at high speed and worsens the commutation, but it also reduces the stalling torque. Incidentally, the adjustment of the series resistances usually upsets the control for ordinary acceleration from rest and for plugging.

Fortunately, in practice, some kind of a compromise can be obtained which usually provides effective control of the bogie, but the margin for various conditions of load is exceedingly small. The mill-type motor will not commutate well but its sturdy construction withstands the harsh treatment without excessive maintenance.

Figure 12 shows a correct design of diverter control for the ingot bogie. The graduation employed sustains an adequate retarding torque, which can be easily increased or decreased by adjusting the contactors to suit site conditions, without affecting the resistances. The graduation has practically no effect on the field which is maintained at a suitable value in the region of full-load current during the deceleration period. The light-load speed finally obtained is low and the stalling torque high. The values of all resistances are linked mathematically and the design of such control gear should receive great care.

Diverter control systems are in use for controlling the free lowering speeds of hoists driven by compound and even series motors, but the inherent instability of the speed/torque curves in the presence of an overhauling load makes such systems out of keeping with good practice. Further, control of the drive is lost with any diverter system as soon as the power supply is interrupted, and stopping thereafter depends only on the efficiency of the electro-mechanical brake.

SECTION X—DYNAMIC CONTROL FOR SERIES MOTORS

POTENTIOMETER LOWERING AND DYNAMIC BRAKING FOR HOISTS

Potentiometer-Dynamic Lowering

Figure 13 shows the elementary circuit for this type of control. The main contactors 1KO, 1D and M are shown in this Figure in order to facilitate reference to Fig. 8, the complete diagram for the equipment. When compared with the insets of Figs. 11 and 12 it will be noted that the series field and brake have been transferred from the line feed to the branch which diverts the armature. The principal result is a strengthening of field current as the speed increases, instead of a weakening as previously. The speed/torque curves are shown in Fig. 14 and marked "Lower 1," "Lower 2," etc. These are concave with respect to the axis of torque instead of convex as in Figs. 11 and 12, and have an inherent stability against overhauling loads.

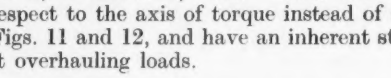

Fig. 13—Connections for series motor for potentiometer dynamic lowering

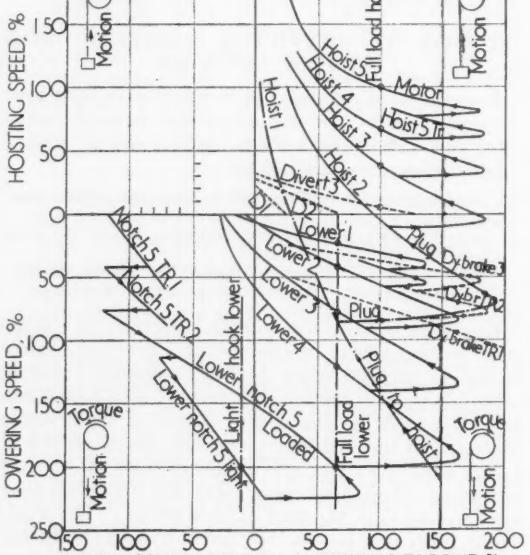

Fig. 14—Speed/torque curves for dynamic lowering hoist

The elementary circuit of Fig. 13 is used to obtain the characteristics of the first four lowering notches. The variation between the four curves is obtained by changing the values of the resistances in the parallel branches of armature and field, the line resistance remaining constant. If the curves are produced backwards into the top left-hand quadrant of Fig. 14 the armature is rotating in the direction for hoisting but it exerts a drive-down torque. If any one of the family of curves is traced through this quadrant the torque will be found to rise to a maximum and then decrease asymptotically similar to Figs. 11 and 12. However, the performance for the crane hoist is required instead in the bottom right-hand quadrant where the movement is lowering and the motor torque is hoisting, *i.e.*, suitable for sustaining the load. It will be seen that a very wide range of speed control is provided suitable for all loads. The faster the motor is pulled round by the load the greater is the retarding torque developed, and there is no limit to this within the ability of the motor to commutate. This limit is between four and six times the torque necessary to sustain full load. The inherent stability of this arrangement is apparent from the curves, and its value for crane hoists is obvious. It should be noted also that a moderate drive-down torque is available when the motor starts from rest.

On the fifth lowering notch, the line resistance is cut out and the motor is operating as a shunt machine, both field and armature being connected independently across the supply. A large resistance is in series with the field in order to limit the current to a suitable value. The initial armature current is restricted in a similar manner, but accelerating contactors 5R and 6R are used to cut out most of the resistance as the speed rises. Thus a high starting torque is maintained until the motor is well above rated speed, and thereafter the torque changes to any suitable negative value as determined by the load. The starting torque of notch 5 is particularly useful in accelerating the empty hook or small loads and is a valuable time-saver.

Returning to notches 1–4, assume that current flows from L1 to L2 in all branches of Fig. 8, producing a drive-down torque when the motor is at rest. As the lowering speed increases and the counter-e.m.f. develops, the armature current drops to zero and there is no torque. This occurs at 7½% speed for notches 1 and 2, 30% speed for notch 3, and 60% speed for notch 4 (*see* Fig. 14). A further increase of speed and counter-e.m.f. reverses the armature current and the motor develops a load-sustaining or negative torque. The armature current is now passing into the junction (Fig. 13) of line-resistance and field. As current, until this point in the explanation, has been drawn from L1, it may be seen that all the reversed armature current now feeds into the field, and the line resistance supplies only the difference between the field and the armature amperes. When the speed is sufficiently high, the armature supplies the whole of the field current, the line current is zero, and no difference would at this moment be introduced if the line supply were interrupted. If the speed rises still further, there is a surplus of armature current not required by the field, and the armature is then feeding current back into the lines. In practice the dynamic lowering hoist does not regenerate in this manner until full load is lowered at speeds in excess of 150%. To get these higher speeds the motor field is relatively weaker and so does not require so much armature current before there is a surplus available for regeneration.

Potentiometer-Dynamic Lowering on Rectified A.C. Supply

There is practically no change when a dynamic lowering hoist is operated from a rectified A.C. supply and there is no other connected load to absorb any regenerated current. The surplus current is simply pumped into the field branch and lowering continues without much change in speed. On the highest speed notch of a control designed to lower at 200% speed, there would be an increase to 210–215% if full load is being lowered, and no increase at half load or less. There will be a rise in voltage, particularly when the equipment is decelerated from high speed. This will do no harm to the electric equipment of the crane, but may blow the lights. If desired, a ballast resistance can easily be fitted on the line supply which will be cut in automatically on a rise of a few volts and cut out as soon as regenerated current ceases to flow through the ballast.

Dynamic Braking

Referring to Fig. 8 the dynamic-braking circuit is established by the closing of the contacts of 2D in the " off " position, when this switch is de-energized and the line supply is cut off by the opening of the contactors 1KO and M. 2D is a spring-closed and electrically-opened contactor so that, in the event of a failure of the power supply, the dynamic circuit is always established and prevents the load from running away if the electromechanical brake is out of order. Reading the key part of Fig. 8, this safety circuit can be traced from armature lead A, through resistances R5-R6-R7-R8, contacts of 2D, series field YY, and back to the armature at AA. The field is always energized, when the motor is running, in the direction AA–YY, assuming voltage and current flow from L1 to L2. When the motor is being energized for lowering through 1KO, the counter-e.m.f. is from A to AA. If the control gear is in the " off " position and the brake is released by hand the load will pull the motor round in the direction for lowering, the residual field will cause an armature e.m.f. as normal for lowering in the direction A–AA, and this causes a current to flow through the field in the direction AA–YY. This is the correct direction for increasing the field and dynamic braking is thus cumulatively established. The same circuit exists when the motor is switched off while hoisting, but the armature e.m.f. tends to destroy the field and no braking is obtained.

The crane safety limit switch, also shown in Fig. 8, is used to reverse the armature connections with respect to the field and thus to obtain a quick stop independent of the electromechanical brake should an overwind occur. The great advantage of this switch compared with a shunt or plain series limit switch was discussed on page 276 of the February, 1947, *Journal*, and its action can be traced from this diagram and the above explanation.

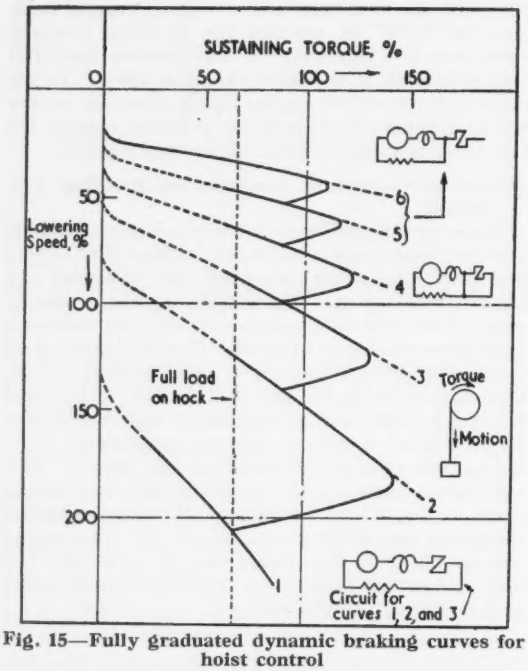

Fig. 15—Fully graduated dynamic braking curves for hoist control

Reference was made in the sub-section on graduated braking on cranes to single-step dynamic braking for hoists. Mechanically this is quite sound and the special system of connections used both for drum controllers and contactor panels enables a single contact to carry out this task. On the former, single-step braking is standard. On the I.T.L. equipments the contactor 2D alone is used for small motors, but on all larger equipments 3-step braking has been standard for many years. The intensification of the braking obtained by this means further reduces the wear on the electromechanical brake and the speed at which the load could descend if the brake went wrong.

Three-step braking is used on the equipment shown in Fig. 8. The dynamic current produces a voltage across resistance R7–R8. This energizes the coil of the relay VR connected across it. The operating coils of resistance contactors 5R and 6R are fed from control line 15, through the " off " position of the master drum and finger 12, through the transient closure of VR contacts 93–94 and the interlock contacts of 2D to line 16. During dynamic braking, therefore, 5R and 6R close under I.T.L. control after 2D has established the dynamic circuit. In Fig. 14 the three dynamic braking curves are shown by the broken lines marked " Dy : Brake Transition 1," " Dy : Br : Transition 2," and " Dy : Br : 3."

Even 3-step braking is a severe test of commutation. It is just within the capacity of an industrial motor on 220 V. if the lowering speed is limited to 150%. 440 and 500 V. supplies are of increasing popularity owing to the need to save copper, and there is growing demand for lowering speeds of 200%. Consequently a fully graduated system of dynamic braking has recently been standardized on all the best I.T.L. equipments. This takes place in five or six steps and was formerly only used for special high-speed lowering, such as quenching cranes which lower full load at 250% speed, for industrial motors on 500 V. supplies, and for grabbing cranes.

The general adoption of fully graduated braking will make commutation very easy for mill-type motors and comfortably within the capacity of industrial motors on all voltages. Another advantage is introduced by the inclusion of the series brake coil within the dynamic loop during the earlier stages of braking. The electromechanical brake is thus held off until the motor speed has been much reduced. The wear of the linings is nearly eliminated and the brake preserved in good order for its principal function of holding the load. On grabbing and similar severe duty the fully graduated braking enables a normal size of brake to be used instead of the over-size which is otherwise necessary.

Figure 15 shows the braking curves only for a hoist equipment which is provided with fully graduated dynamic control in the " off " position. When used after lowering at high speed the motor is disconnected from the power supply, but all resistance contactors are arranged to close in sequence under I.T.L. control, thus reducing the resistance in the dynamic loop and rapidly reducing the speed. Six curves are shown, and the connections are such that the dynamic current is circulated through the brake coil until the fourth is reached. At this point in the sequence the current by-passes the brake, which is momentarily short-circuited without any interruption of the dynamic loop. The brake coil is open-circulated immediately after the current is transferred out of that branch. The electromechanical brake is therefore applied between the fourth and fifth curves, most of the stored and potential energy being absorbed by the motor prior to the application of the shoes.

It will be noted that the curves of dynamic braking in Fig. 15 are very similar to those of power lowering in Fig. 14. In both methods the armature current during deceleration assists in forcing the field and the characteristics are inherently stable and independent of the maintenance of the electrical supply. This is a very different state of affairs from that of the diverter system discussed in Section IX.

As mentioned on page 365 there is no need to plug a crane hoist. If a good system of dynamic braking is in use, a quicker stop can be achieved after lowering by simply switching off.

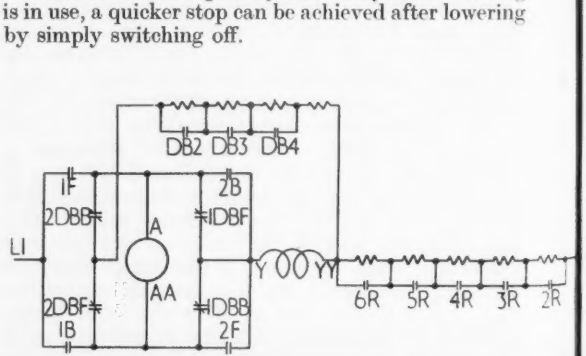

Fig. 16—Dynamic braking for single series motor

DYNAMIC BRAKING FOR PLAIN REVERSING DRIVES

Single Motor Braking

Figure 16 contains the main circuit diagram of a long-travel crane drive using CondITLe control, with certain additions. These are the components necessary to provide graduated dynamic braking on a simple reversing control for a series motor, and they comprise :

Four spring-closed contactors which may be considered in pairs, namely, 1DBF and 2DBF which set up a braking loop which is cumulative after forward running (*i.e.*, the direction in which contactors 1F and 2F supply power), and 1DBB and 2DBB which set up a braking loop which is cumulative after backwards running.

Three resistance contactors DB2, DB3, and DB4 which close under I.T.L. control after dynamic braking has been established, thus providing the graduation.

A solenoid-operated latching device, not shown on the diagram, which sets in one of two positions according to the direction of travel. The solenoids rotate a shaft which carries cams. These operate on the four spring-closed contactors so that only one pair can close at a time although all four are de-energized in the " off " position. By this means the appropriate pair of contactors closes after power is removed from the motor, and the armature e.m.f. passes current through the field in the direction Y–YY, which ensures cumulative action.

In view of the explanation in the preceding subsection it is unnecessary to trace the dynamic circuit. It is sufficient to mention that after 1F and 2F have operated the motor for forward running 1DBB and 2DBB are prevented from closing contact in the " off " position, and likewise 1DBF and 2DBF are locked out by the cams after the motor has been driving backwards.

When the machine is at rest and is moved by an external force, dynamic braking occurs only in the one direction. This arrangement is, therefore, not alone adequate for the travelling motion of an outdoor crane where wind is troublesome.

Two-Motor Braking

If, in Fig. 16, 1DBB and 2DBB were removed and applied instead to an identical position on a second motor and, if also, no latching mechanism were adopted, all four contactors would close in the " off " position and dynamic braking would be available in each direction but only from one motor.

However, a better arrangement is shown in Fig. 17 known as the Wilson-Ritchie system of dynamic braking for a two-motor drive with series motors. The normal series resistances have been omitted for simplicity, as have also the graduating contactors for the braking resistances. The four dynamic braking contactors, electrically opened as previously, all close contact by means of their springs in the " off " position ; they are marked 1DB, 2DB, 3DB, and 4DB. In the lower circuit the armature is reversed and the field energized in one direction as in standard diagrams given earlier. In the upper motor circuit

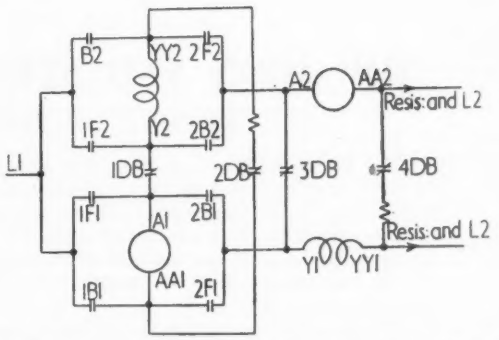

Fig. 17—Dynamic braking for 2-motor drive, Wilson-Ritchie system, series motors

the field is reversed and the armature energized in one direction. Consider first, the action of the dynamic loop, Y1–YY1, dynamic resistance, 4DB contacts, upper armature AA2–A2, 3DB contacts, and back to Y1. Because the reversal of the field Y2–YY2 is used for obtaining the direction of travel of the upper motor, the counter-e.m.f. of the armature is always from AA2 to A2 assuming the line voltage operates from L1 to L2. Thus in braking, the counter-e.m.f. of AA2 to A2 circulates current through Y1 to YY1, and this is the correct direction for maintaining the counter-e.m.f. of the armature of the lower motor. After forwards running this was in the direction AA1 to A1. But it will be seen that for forwards running the field of the upper motor was energized from Y2 to YY2. The counter voltage in this dynamic circuit from AA1 to A1 passes current through 1DB contacts and the series field of the upper motor Y2 to YY2, the dynamic resistance, the contacts of 2DB, and back to AA1. In this way the lower armature sustains the upper field. For backwards movement, as the counter voltage is A1–AA1 and the field YY2–Y2 the connections of the dynamic circuit are also correct.

By the above means both motors give dynamic braking after switching off for either direction of travel and the system may be graduated if desired. Furthermore, the clumsy latching gear which was necessary for the single motor has been eliminated. For two-motor drives, therefore, the Wilson-Ritchie dynamic braking is recommended. It is particularly valuable for use out of doors, as it is effective in both directions without the power supply. For the cross-traverse motion of an orebridge it may be used as an alternative to plugging for safety and economy of power. It is not usually regarded as a substitute, as 2-step or 3-step plugging is still preferred by drivers for really fast work and accurate spotting over transfer cars.

In conclusion the author would like to thank the directors of the Igranic Electric Co., Ltd., for permission to publish the details given in this paper, and his colleagues, for assistance in its preparation.

The above paper is one of three to be presented at the Seventh Meeting of the Iron and Steel Engineers Group, to be held in London on Wednesday, 9th June, 1948.

The other papers, on Electronic and Servo Controls and their Application to the Iron and Steel Industry, by W. G. Thompson, and on the Maintenance of Electric Machinery in Iron and Steel Works, by G. S. Martin, and M. Y. Harvey, will be published in the April issue of the *Journal*.

THE IRON AND STEEL ENGINEERS GROUP

REPORT OF THE FIFTH MEETING

The Fifth Meeting of the Iron and Steel Engineers Group of The Iron and Steel Institute was held at 4, Grosvenor Gardens, London, S.W.1, on Wednesday, 26th November, 1947. Mr. W. F. Cartwright (Steel Company of Wales, Ltd.) occupied the Chair.

The Morning Session (10.30 a.m. to 12.45 p.m.) was devoted to discussion on the paper "Mechanical and Electrical Features of Primary Hot-Rolling-Mill Auxiliaries," by W. W. Franklin and P. F. Grove. Two aspects were considered: (1) mechanical features and (2) electrical features.

The proceedings of the Afternoon Session (2.0 p.m. to 4.30 p.m.) were published in the February issue of the *Journal*.

PROCEEDINGS OF THE MORNING SESSION: 10.30 a.m. to 12.45 p.m.

Discussion on MECHANICAL AND ELECTRICAL FEATURES OF PRIMARY HOT-ROLLING-MILL AUXILIARIES*

Mr. **W. W. Franklin** (Davy and United Engineering Co., Ltd.), in introducing his paper on "*Mechanical Features*," said: The auxiliaries of a heavy mill plant soon assume major importance if they fail to deal with the output of the mill or if, owing to indifferent design, they need constant maintenance. The cost of maintenance can be very quickly reflected in the cost per ton of finished product, and therefore additional capital expenditure is well spent if it ensures equipment that is always up to its job with a minimum of attention. Modern mill machinery is more expensive (even if we were operating under, say, pre-war price levels) by reason of the refinements that reduce maintenance, power consumption, and mill labour.

The demands of steelworks engineers are continually becoming more exacting, and it is in reply to these demands that mill builders have built up their designs to the present level. In other words, the steelworks engineers dictated the ideas, and the mill designers incorporated and perhaps elaborated them. Steelworks engineering never stands still; each job installed is in some respects better than its predecessor.

In preparing this paper these thoughts were in mind. Obviously, there must be a wide divergence of opinion on the suitability of various designs, hence alternatives for each auxiliary are described.

(Mr. Franklin then outlined the contents of his paper, which covered alternative designs of roller tables with plain and roller bearings, hydraulic and electric manipulators, breast-roller drives, screwdown gears, and hydraulic and electrically driven bloom shears.)

Mr. **P. F. Grove** (John Miles and Partners (London), Ltd.), in introducing his paper on "*Electrical Features*," said: It may seem strange after all these years of operating blooming, cogging, and slabbing mills, that we are only now discussing the electrical features of their auxiliary drives. The standard mill-type motor has changed very little since its introduction some thirty years ago. The main changes are in the use of rolled and welded steel frames by some makers, roller bearings and, occasionally, fixed cable boxes. Of its rating very little has been said and, apart from standardization of a range of ratings to correspond to American standards, which was largely brought about by the American engineers over here before the war, the usual 1-hr. and ½-hr. ratings still apply.

Concentration in the past has been on the main drive, and the only direct work I can remember on auxiliary motors is that referred to in a paper written by Umansky as long ago as 1922. I remember also one other short article in the British electrical press showing how to work out R.M.S. ratings. In his paper, Umansky pointed out the necessity of studying the effect of WR^2 of the drives in order to lessen troubles which were taking place in those days with mill auxiliary motors.

The fact which I wish to draw out is that it should be possible to work out schedules of work cycles just like we always have done for the main roll drive and base our auxiliary-motor ratings on these, thereby abandoning the arbitrary 1-hr. and ½-hr. ratings, or the percentage ratings which crept in from abroad and led to confusion and mistakes. I have made a whole-hearted plea for Ward-Leonard control for all primary-mill auxiliaries, and there may be some comment here, asking what is wrong with the present constant-voltage D.C. motors and perhaps questioning the extra cost.

The paper covers also the arrangement of control equipment and embraces cabling and lighting as being within the sphere of the primary-mill group, looked at as a production unit.

(Mr. Grove then gave a summary of the paper and showed a number of slides. These illustrated respectively the features of typical mill-type auxiliary motors and brakes, methods of cabling, ducting for forced ventilation, some examples of British mills with Ward-Leonard drives, and suggestions for combined-type control desks, the latter being taken from non-ferrous mill practice. Mr. Franklin's point about the elimination of trailing cables when tilting-finger motor drives are fixed to the foundations was illustrated by pictures of typical mills employing either fixed or moving equipment. Mr. Grove illustrated his own point concerning safety of enclosed electric machinery, with slides showing typical open and alternatively enclosed types of control panels.)

Mr. **A. Taylor** (South Durham Steel and Iron Co., Ltd.): I would like first to congratulate Mr. Franklin on his very able paper on the mechanical features of rolling mills. I think it will be generally agreed that, so far as design is concerned, we can get a first-class job today, but in dealing with any particular mill, one ought first of all to take into account load considerations, which are often very important. I usually pay great attention to what happens in the basic operational conditions, as, for instance, the starting up of the mill on a Sunday

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evening. The mill may have been off for repairs, adjustments, and so on ; then the operators come along, set the rolls, and in a comparatively short time, one finds a difficulty. It may be found that when the mill has started rolling—I am thinking of a plate mill—and the steel is not quite up to temperature, the first ingot or slab is usually subject to some delay with the result that there is localized heat in the breast-roller drives or near-approach tables. From that angle alone, I feel that we should pay greater attention to the expansion in bearings and drives.

On the question of lubrication, I think the tendency today is for flood lubrication, with the qualification that prior to the starting of the mill the lubricant should be well flushed round the drive which it has to lubricate.

I do not think we pay quite the attention we ought to the details of the fore-plate adjustment. We often leave that to the operator. He comes along to set up his rolls ; he may lift the bottom roll or dip it, as the case may be (by means of putting in or taking out packings which are by comparison very crude, particularly in a highly mechanized mill), with the result that the bar is not delivered properly from the mill rolls. Thus, coupled with the fact that the slabs may not be uniformly heated, all sorts of unusual things occur. Breast rolls are damaged in the first few hours or mill tables are overloaded. We, the engineers, should give the operator far better means of adjusting his fore plate to save damage to the tables and breast rollers.

On the general question of design of tables, I think we are coming back by degrees to the simple white-metal-lined bearing. The roller bearing is very good, and it must be accepted as being a first-class job for certain conditions, but in heavy mills there are inevitably variations that do prevent quick repairs being made in the event of a failure.

There is one other point I want to mention as a matter of detail. Wherever possible bolt dimensions should be standardized. That is not always possible over a wide range, but it can be done very effectively within limits, which means that during any failure a minimum of time is lost by the mechanic in getting to the " seat " of the trouble to effect the repair.

I have also found—I am quoting my own experience now—that even in the most modern tables there is always a tendency for settlement immediately adjacent to the mill, either front or back, and having that in mind I have adopted the practice of putting a grillage underneath the main frame so that any localized shocks or settlements are distributed right through the mill and table foundations, because settlement is invariably due to continuous impact on the approach tables.

Dealing with the control of mills, particularly screw-down, wherever it is possible Ward-Leonard control should be used, because one often finds overloads occurring for no apparent reason. I have in mind a particular case which occurred recently, where a slab was being broken-down with the mill not fitted with Ward-Leonard control, and clearly what happened was that the operator overran his mark. After all, without Ward-Leonard control, the operator has to use a fair amount of judgment. With Ward-Leonard control that is reduced to almost zero, giving more precision rolling in accordance with the schedule of draughting and reducing the possible serious overloading which may result in roll breakages or damage to mill equipment.

Mr. **W. W. Franklin** : On the subject of fore plates, I agree that there is scope for more collaboration, shall I say, between the builder and probably the steelworks engineer, at the same time bringing the operators into the discussions. I think that often where the trouble arises is that the operator himself is not consulted in the early stages of the design of a new mill to ensure that he gets exactly what he really requires. I think we should all benefit by using the operator's experience in the initial discussions of these various details.

On the question of roller bearings, from what is said in the paper I think it will be appreciated that I entirely agree with Mr. Taylor. Probably there will be other remarks on that matter.

The putting of grillage under the tables is a very good point and should materially assist in spreading the load. I have not had any personal experience of this, but it sounds an excellent suggestion.

Mr. **H. S. Carnegie** (English Electric Co., Ltd.) : There seems to be a difference of opinion between the two authors on the desirability of the mill tables working towards or away from the mill. I wonder whether that matter is really influenced by the type of drive. Most mill tables are driven by series motors. So long as those are connected in the direction that a mill is going, there is no braking effect whatsoever. No matter on to what notch you put the controller, you cannot, as Mr. Grove suggests, put it on to a lower notch and obtain a braking action. Owing to the characteristics of the series motor, in order to brake, the motor must be run in the reverse direction. In the case of another type of drive, either with compound mill motors, which perhaps are not quite so desirable, or better, with Ward-Leonard control and shunt motors, the rollers could then be run rather slower than the pieces being ejected from the mill in order to get braking. If the practice of using series motors does not affect the question, but that the reverse rollers do give a quicker pull up of the piece than if you are rotating them in the same direction as the mill, why does it not apply to other drives such as locomotives or trams ? I think the point depends partly on the drive.

I agree that individually driven breast rollers give the best drive, but I am inclined to favour indirectly coupling them to the mill. There are several successful installations of that type. I favour using a low-speed motor with the elimination of gearing and the slipping clutch, to which Mr. Franklin refers in his paper.

Mr. Franklin refers to the breast rollers rotating towards the mill on the outgoing side, and says that if they rotate with the mill they may drive the piece a considerable distance down the tables before it can be stopped. Surely that should not be the proper operation of a breast roller. If the table rollers be operating more slowly than the piece or towards the mill, in either case giving a braking effect, the breast roller should not have any appreciable effect. Since it is primarily a feed roller, and also a guide or deflector on the outgoing side, surely that suggests that the breast roller should be rotating away from the mill on the outgoing side.

I am in favour of the measurement of temperature rise of mill motors by resistance rather than by thermometer, particularly for short-rated motors. In the case of a ½-hr.-rated totally enclosed mill motor, or even a 1-hr. forced-ventilated mill motor, the accepted temperature rise, measured by thermometer, of 75° C. means a temperature rise which, if measured by resistance, is about 110° C. Surely one should measure temperature rise by the means which gives the closer approach to the actual conditions prevailing. I suggest that if temperature rise measured by resistance be accepted, a figure of 105° C. can well be accepted. In a continuously rated motor there is, however, much less difference between the measurements of temperature rise by the two methods.

I agree completely with Mr. Grove's advocacy of the R.M.S. cycle instead of using the ½-hr. or 1-hr. rating.

The two important ratings in a mill motor should be the *heating* and the maximum torque, and these are obtained by an R.M.S. rating and a maximum torque. The same point was brought out in a recent paper by Sadler* on somewhat similar types of drives, namely, on cranes. Those points, of course, are not the only ones to be considered when determining the size of any of these auxiliaries ; besides the heating and the peak torque, there must be sufficient sustained torque during the acceleration to get the roller or piece up to speed in the minimum time, but there must not be an excessive torque, otherwise the piece may skid and be even slower than if you accelerated at a lower rate. It seems, therefore, that there is a rather definite maximum torque that should not be exceeded on roller-table drives. In addition, of course, a good braking effect is required when decelerating, but it must not be too snappy, otherwise, again, the piece will skid, and not be brought to rest quite so quickly.

Mr. Grove mentions some of the well-known amplifying or quick-acting exciters. I would prefer those terms to the trade names of the five mentioned. They are very useful control items. They are not the cure-alls that one might have inferred from reading some of the articles in the American press. In some cases " shovel "-type generators are preferable to generators indirectly controlled by quick-acting exciters.

Normally a series type of motor cannot be used with Ward-Leonard control, unless with a reversing contactor gear. However, a new method to which I was rather attracted *can* do that by feeding the series field winding through a bridge-connected rectifier, so that the series field is always in the same direction, no matter which way the current flows in the armature. This seems to be a useful method. For example, it might be employed on ingot buggies, with either Ward-Leonard or constant-voltage supply, and may save conductor bars.

Mr. Grove refers at the conclusion of his paper to earthing protection of plug points. I would like to advocate another safety method in the use of small step-down transformers for all portable lights or small electrical apparatus giving a voltage of not more than 50 V. There are normally a good many failures of flexibles and apparatus where portables are in use, but using 50 V. or less for those items, you cannot then have a fatal shock.

Mr. **P. F. Grove** : On the question of whether the outgoing rollers should feed inwards to the mill, it is perhaps difficult to visualize what the problem is, but from the simple point of view, I feel that it is possible to feed the piece into the rolls and lead it out again under full control as Mr. Carnegie has explained. Then I think the difficulty disappears.

On the question of exactly at what speed the breast rollers should run, I see the ingot coming along the roller tables, when it is taken over by the breast rollers at a speed which is suitable to match with the main rolls, and then it could be received from the main rolls on the roller tables by a smooth controlled action which is different from what we have been used to. I think that if there is Ward-Leonard drive right through the mill, the operator will be able to feel the piece through very much more easily. I hope I have got that point clear.

I am glad that Mr. Carnegie agrees with my suggestions about R.M.S. rating, but I did forget to mention again in my introductory remarks the two other important factors, namely, the peak rating and the rate of acceleration. The rate of acceleration can be calculated from the WR^2 of the motor and drive, but the peak is more difficult and that will have to be found out by test.

I was interested in Mr. Carnegie's mention of the series motor winding fed from a rectifier, and applied to ingot buggies. We did not bring ingot buggies into the paper, but one of the greatest difficulties from the electrical side is the conductor bars. They are difficult when in a tunnel underneath because scale gets dropped down the slot. The Americans generally put them up along the side of the soaking pits, which I think is very dangerous. There are sometimes a great number of conductors and if the idea mentioned by Mr. Carnegie tends to make for fewer conductors, I am all for it. It seems to me to be a good combination of traction series-drive with Ward-Leonard drive, neither of which is quite suitable in this case without the other.

With regard to plug points, the use of earth-leakage protection referred to in the paper really refers to a scheme using a mid-point-tapped transformer which was developed for portable hand-tools at 230–250 V. This can be demonstrated to be safe under all conditions, but I agree that voltages of not more than 24–50 V. are entirely to be commended.

Mr. **W. W. Franklin** : I should like to clear up one point. Perhaps the use of the words " reduction gear " in connection with the breast-roller drive is somewhat of a misnomer. A slow-speed motor can be used there just as readily, and I agree probably with more efficiency. The words " reduction gear " should probably have been just "gear-box," the idea being that the motor is coupled to a central pinion or wheel and then driven each way, one drive going to the breast roller and the other drive to the first roller, so that one powerful motor drives the two rollers, and not just the breast roller.

On the question of coupling the control of the breast roller and the first roller with either the main table or with the mill, there are still a lot of difficulties. The fact remains that I have seen it on mills, as, no doubt, some people here will confirm, with the outgoing table run in towards the mill when the piece is leaving the mill to prevent it from getting too far away from the pass, and to speed up the return journey. There must be a very severe brake effect, owing to the fact that the motor is motoring in towards the mill. If the breast roller is coupled to the mill the tendency to throw the piece further away from the pass is increased, whereas if it is coupled to the tables the condition is improved. I am inclined to agree that the best solution is an independent control for the breast roller and the first roller, so that there is absolute control over whatever it is required to do.

Mr. **T. Coxon** (Consett Iron Co., Ltd.) : Mr. Grove pays considerable attention to the simplification of the operation of main mills. I see no reason why, once the ingot is on the ingoing roller table, the operation of a complete modern mill should not be in the hands of one operator. The approach to the ingoing rollers and the following of the ingot through to the shears could be under the control of a second operator.

Dealing with the question of bearings for mill-auxiliary motors, I think it is accepted that most new plants will have roller bearings. This feature introduces certain complications, particularly with drives also fitted with roller bearings.

Can Mr. Grove state whether or not the present run of mill auxiliaries has a location bearing designed to take a considerable degree of thrust ?

Mr. Grove says that it is preferable to have a flexible drive. In the case of mill auxiliaries with ball or roller bearings, it is essential to have flexible couplings. Further, with the present permissible temperature rise of 75° C., measured by thermometer, with motors that

* G. V. Sadler, *Journal of the Institution of Electrical Engineers*, 1948, vol. 95, part 2.

can be coupled up at either end and where the distance between the location bearing and the coupling is of the order of 50–60 in., it is possible to get, between the cold and hot conditions, a movement of the coupling, and hence a reduction of coupling clearance, of the order of $\frac{1}{16}$ in.

Should the maintenance people be presented with a drive that has a normal coupling clearance of $\frac{1}{16}$ in. "cold" and hence practically no clearance "hot," complications may arise since there is the possibility of a replacement "cold" motor being lined up with "hot" clearance, resulting in enormous end thrust on all location bearings.

With reference to cable arrangements, while the present general practice with regard to cables is untidy, I think that it is the one method which enables motors to be changed easily and without damage to the cables. With terminal boxes it is a very difficult job to have a suitable connection between the armoured cable and the terminal box, particularly since some degree of flexibility is necessary to permit alignment. I should like to make a further point that where terminal boxes are employed the boxes should be constructed of steel, preferably integral with the box frame.

Where "tails" are employed I would suggest that there should be a small cast steel cowl over each cable outlet, so that the cables may be bent down sharply without being sheared off or broken.

With regard to temperatures, the present practice—as Mr. Carnegie pointed out—is 75° C. rise, measured by thermometer, with the corresponding increase by resistance. It appears to me that a new British Standards Specification is desirable, to give the C.M.R. rating of all motors. The present tendency is to standardize, and it is suggested that the American short standard be accepted as the common standard throughout the industry.

Also, since magnitude of overload and duration of overloads are functions of the temperature–time constant, it would be useful for such a specification to give the temperature–time constant of the machines, on the lines given in British Standards Specification No. 171 for transformers. The WR^2 of machines would also be most useful.

With modern mills having roller bearings throughout, the question of selecting a motor appears to be a much simpler job than before, particularly with Ward-Leonard drive. One of the features of Ward-Leonard drive is that the current peaks, inherent with the contactor type of controller direct from the mains, disappear, and so with roller or ball bearings throughout, the drive is one to overcome the inertia of the system more than the actual loading conditions; that is, on an ingoing roller table the power required to accelerate the roller table is not materially altered when the ingot comes on the table. Hence, with a fast-working mill it appears that the machine required is one with a C.M.R. rating equated to the torque required, to overcome friction and acceleration, and to the normal speed of feed to the mill.

Mr. **P. F. Grove**: In answer to Mr. Coxon the simplifications referred to in the paper are more concerned with electrical equipment than with the number of operators. I do not think we can reduce the number of operators, nor do I think that we shall want more under the proposal suggested. The question of fully automatic control needs some further consideration.

The point about roller-bearing thrust is one on which the makers might like to comment. To my knowledge most designs of mill-type motors have a small thrust ring only, and the question of any serious end thrust has not arisen when using flexible couplings.

Mr. **W. J. Pool** (British Thomson-Houston Co., Ltd.): Mr. Grove has commented on the illogical nature of the standard short-time rating of mill-type motors, and has shown how the equivalent continuous rating corresponding to a continuously repeated duty cycle can be calculated.

I agree that many rolling-mill-auxiliary duties are better represented by an equivalent continuous rating than by a 1-hr. rating, but I am afraid that we should run into some serious practical difficulties if at this stage of development we were to attempt to standardize continuously rated instead of 1-hr.-rated mill-type motors. Considerations of cost would almost certainly force designers into a different kind of design, *e.g.*, frames would be designed for a maximum radiating capacity, and the difficulties of ensuring interchangeability with American machines would be greatly intensified. Moreover, except for the smaller sizes, continuously rated totally enclosed machines tend to become too cumbersome and their inertia becomes embarrassing, as explained later.

I suggest that the necessity for forced ventilation on heavy duties should be accepted; that the present 1-hr.-rated machines should remain available for really intermittent duties; and that the same machines should be used to give the same horse-powers continuously with forced ventilation for the more severe duties.

Mr. Grove urges that more tests should be taken on auxiliary drives to determine the ratings required. Whilst I agree, I feel that far more might be done than is at present the case by co-operation between the electrical manufacturers and the mill designers, for the selection of the most suitable motor in view of the inertia of the parts to be driven, frequency of operation, expected friction load, etc. There is some risk in applying the results of tests to other not quite analogous cases unless the theoretical basis is thoroughly understood and the above physical factors are correctly evaluated and used.

I should like if I may to amplify what Mr. Grove has said with regard to the calculation of the equivalent continuous rating of a motor working on a duty cycle involving starting and stopping. It cannot be too clearly understood that in such cases the inertia effect is often the most important source of load, and it is essential that this inertia load should be used in calculating the R.M.S. rating.

An example from a recently installed cogging-mill screwdown will make this clear. The power necessary to drive the top roll down against the hydraulic balance is about 70 h.p. total. However, the chief duty of the motors is to drive the rolls down in steps of, say, 2 in., completing each movement in $1\frac{1}{2}$–2 sec. Under these conditions the motors never experience this steady load of 70 h.p. Each movement consists of a rapid acceleration followed at once by a rapid retardation, and as the power required to accelerate and retard the motors and mechanical parts at the required rate is about 350 h.p., it will be seen that the motors are subjected to loads of 420 h.p. motoring, followed by 280 h.p. regenerating. It is not surprising therefore that the R.M.S. rating required is 240 h.p., which, as will be seen, is due almost entirely to inertia forces.

A further point arises from this example. The motors are forced-ventilated, but even so they account for about 50% of the inertia. Totally enclosed non-forced-ventilated motors of the same rating would have several times the inertia, which would greatly increase the R.M.S. horse-power; this would in turn necessitate still larger motors with still higher inertias. In fact the proposition would become impracticable. In cases of this kind forced

ventilation is not simply a refinement ; it is an absolute necessity.

I should like to endorse much of what Mr. Grove has said on the subject of control desks. This item merits at least as much attention as any other part of the plant, since the comfort and convenience with which the operator can carry out his duties may well have a direct effect on output. The closest co-operation between the electrical manufacturer and the ultimate user is called for, and experience based on many desks supplied both to the steel and to the light-alloy industries shows that the great amount of forethought and care put into the design is amply repaid. This applies chiefly to cases where there is one operator per desk controlling a number of movements. Where two or more operators are concerned greater flexibility is required, and I agree with Mr. Grove that it is very desirable to try out the proposed arrangement in practice before it is put into permanent form.

I do not agree with Mr. Grove's statement that for proper isolation and safety only total enclosure of contactor panels can be recommended. On the assumption that in either case the control gear is housed in a room which can be kept clean and is accessible only to the electrical staff, I feel that open-type panels definitely permit of easier maintenance, and where maintenance is easier it is likely to be more thorough. As far as safety is concerned, it is quite certain that sooner rather than later the attendant will want to observe the operation of the equipment with the cubicle doors open, and he will then be at the disadvantage of being more or less surrounded by earthed metal.

Cubicle enclosure is sometimes preferred on the score of appearance. A neat compromise can be made by mounting the contactors on open-type panels, and by providing in front of them, allowing plenty of room for a walk way, a dead front board carrying instruments and control switches. The walk way between contactor panels and dead front board can be kept locked, all that is necessary for routine operation being available at the front of the latter.

Mr. **P. F. Grove** : There does not seem anything for me to answer in Mr. Pool's remarks, because I agree with him. In listening to him and to previous speakers, it seems that this duty-cycle question is one that almost calls for another paper. It is a difficult question, and there are at least three variables in it. I would like some views from the mill men and to hear from them how this suggestion about rating strikes them from the practical point of view.

I agree that forced ventilation is entirely necessary and perhaps I was too cautious, because in the past people have said that forced ventilation means more losses. It is, however, coming into most industries where there is a very heavy type of varying drive.

Mr. **W. A. Johnson** (United Steel Companies, Ltd.) : The electrical engineers seem to have held the field mainly thus far, and I would like to make one or two comments on the last main paragraph in Mr. Franklin's paper and to ask him one question.

The brief reference to flame cutting is interesting, and provides recognition of the fact that the field of application of this process is fundamentally similar to that of shearing. Whilst both methods can be applied to the cutting of structural and other shapes, they are more readily applicable to the cutting of regular solid sections, such as blooms, slabs, and plates. The development of hot flame cutting is of recent origin, but there are a number of installations already operating both in this country and in the United States of America.

The chief advantage of the flame-cutting process lies in its ability to cut sections outside the capacity range of mechanical plant, and this advantage is, of course, more pronounced in regard to cold cutting, as the capacity range of shears is considerably extended when dealing with hot sections. For the cutting of such sections as fall within the capacity range of shears, flame cutting is in general slower and uneconomical as compared with shearing, and the possibility of the rate of oxygen cutting approaching that of shearing would appear to be remote.

Taking an 8-in. sq. section as a fairly common size of bloom leaving the cogging mill, the time required for hot-cropping this section with present flame-cutting equipment is approximately 30 sec., as compared with about 3 sec. for modern shears. Recent developments in regard to low-pressure blowpipes indicate that there are prospects of the cutting time for this section being reduced to approximately 16 sec. Even at this lower figure the disparity in cutting times is still too great for mills having a high rate of output, and five cuts per minute, which can readily be obtained by the use of modern shears, would be quite unobtainable by flame-cutting methods unless a further substantial reduction in cutting time can be achieved. The effect of substituting a single-burner flame-cutting unit for shears in many instances would be to restrict the output of the mill. In some cases the effect can be mitigated by having two or more burners operating simultaneously, although this may well lead to further complications.

Quite apart from the ability of flame-cutting equipment to deal expeditiously with large outputs, the present price of high-purity oxygen renders the process uneconomical as compared with shearing. The capital cost of shears may well be twenty times that of flame-cutting equipment, but when the long life and high rate of output of shears is taken into account, the effect of capital charges and depreciation is insignificant.

On the other hand, for a mill output of 200 ingots per 8-hr. shift, each ingot involving three cuts after rolling into 8-in. sq. blooms, the cost of oxygen alone is equivalent to the total operating cost for shears. Investigations show that the cost of flame cutting and shearing would be approximately equal for a weekly output of about 1000 ingots rolled into 8-in. sq. blooms and each involving three cuts. Below this figure flame cutting would be more economical than shearing, but for higher outputs shearing becomes increasingly cheaper. The economic use of flame cutting therefore appears at present to be restricted to low outputs, where full advantage cannot be taken of the potential rating of shears, or for dealing with sections outside the capacity range of mechanical plant.

The comparatively low capital cost of flame-cutting equipment may warrant consideration of this method as a standby in the event of breakdown of mechanical plant, although the reliability of such plant would hardly appear to justify such a measure in most cases. In a word, I think that the day will come when, with cheaper oxygen and faster cutting methods, flame cutting will be distinctly competitive, having regard to the high capital cost of shears used for some purposes today.

The question I would like to ask is this : There appears to be a theoretical case, and some experimental evidence, for there being a finite lateral clearance between the pair of blades of a shear when cutting cold material. A cleaner cut appears to be produced. I would like to know if Mr. Franklin has given any practical application to this point in the design of shears for cutting cold metal.

Mr. **W. W. Franklin** : On the question of flame cutting, I greatly appreciate all that Mr. Johnson has said, and I agree with him 100%. There are developments taking

place in regard to flame cutting, and some experimental work on it is being carried out. I threw out the thought in the paper in order to see whether anyone had any further experience in the matter. I feel that, although it may be a long way ahead, there may be a future for flame cutting, and that it may replace bloom shears. I would like to know whether anyone else has any experience of the development of flame cutting.

With regard to Mr. Johnson's question, I am afraid I could not quite get the drift of what he meant. He referred to the lateral clearance between the shear blades.

Mr. **W. A. Johnson** : I am suggesting that there may well be, with advantage, a finite clearance between the two blades dependent on the thickness of the material being cut. I believe that if the clearance, in the case of cutting, say, a 4-in. billet, were of the order of $\frac{1}{16}$ in., a cleaner cut might very well be the result.

Mr. **W. W. Franklin** : I have not seen any cold shear where the blades are set with a finite lateral clearance, and would imagine that any such clearance would cause a " fash " or ragged edge where the steel was dragged through the blade clearance. In fact there is a marked difference in the sheared edge when cutting with new blades than when cutting with worn blades. Apart from this the additional side load caused by the use of clearance must surely result in rapid wear of the apron slide surfaces. I should be interested to hear if Mr. Johnson has carried out any experimental work along these lines and to have the opportunity of seeing the results of such experiments.

Dr. **H. Ford** (Paterson Engineering Co., Ltd.) : Perhaps I might intervene on that point. I think the reference is to a paper* that was published in America two or three years ago. It was stated that experimental work had been done on shearing cold strip and sheet, and it had been definitely found that a clearance between the blades—the amount of that clearance depending upon the thickness of the material to be cut—would improve the cutting and reduce the forces involved and also the power consumed in causing the shear.

The **Chairman** (Mr. W. F. Cartwright) : At Port Talbot plate shears were installed in 1914, fitted with adjustable blades, with a card of instructions as to the width to which they should be altered to get the best shearing effect according to the thickness of plate being put into the shears.

Mr. **J. E. Owston** (Thos. Firth and John Brown, Ltd.) : I agree with Mr. Johnson's outlook on the question of mill production being the guiding factor in the economics of flame cutting of hot steel blooms. We have carried out a series of very useful experiments which have resulted in a flame-cutting time of 20 sec. for a single torch on an 8-in. sq. bloom ; by the application of multiple burners, this time can be considerably reduced. At the present moment, we are manufacturing a machine of our own design to instal in a new 28-in. cogging mill. The output of the mill is within the limits that Mr. Johnson mentioned, namely, below 200 ingots per shift ; thus, we feel that the time cycle and the economics will justify the application of flame cutting in lieu of hot shearing.

In this particular case, the flame cutting is purely to crop the discard at the 8-in. square and then to continue with the rolling down to the finished size. For example, starting with an ingot weighing 2 tons, roll down to 8-in. square, crop the discard (which in the case of alloy steels is equivalent to up to 25 or 30%), and then proceed with the final rolling.

On the question of individual motor drive, the general impression has been that for many years the electrical manufacturers in this country have been rather reticent in taking up the individual drive. This is an important feature in heavy mill practice, particularly in connection with the point mentioned by Mr. Franklin, namely, the braking of the bloom as it leaves the mill rolls in order to get it back into the mill rolls in the shortest possible time. The salient point in the mind of the mill operator and the mill manager is that the manipulating time is by far the greater, as against the actual rolling time. The essence of good mill practice, therefore, is to accomplish the reversal of both mill and roller gear within the shortest possible time.

The question of hydraulic as against electrical manipulators is a controversial one ; the average steelworks manager has gradually been driven to the conclusion that hydraulic services and compressed-air services are an expensive hobby, and more and more the tendency is for mills to have individual control, particularly for intermittent operations. As a personal expression of opinion, my view is that the electrical manipulator is far the better proposition.

There is one small technical point I wish to raise. Mr. Franklin states in his paper, on pages 269 and 270, that " The second type is the direct electro-hydraulic drive, which includes a high-pressure hydraulic pump ; this system is also used economically in forging-press practice. . . ." I assume that there he is referring to what we normally call the electraulic system. I should have thought that in heavy forging-press practice it was essential, from the economics of the situation, to have an intensifier rather than a straight electraulic system, the normal applications for such a system being for plate-bending or die-blanking presses. It would be interesting to have some further information on the economics of its application to forging-press work.

With regard to cast steel frames for rolling mills, we have travelled a long way in design since cast steel frames were introduced for the work tables of a rolling mill ; today, the fabricated frame is rapidly replacing castings. It is lighter in weight for equivalent strength and, provided that it is stress-relieved, it is a sounder proposition than the cast steel frame. At the present moment we are manufacturing fabricated frames for work tables on a 42-in. blooming mill.

Mr. **W. W. Franklin** : I agree entirely on the question of fabricated frames. What is rather driving us to fabricated frames is the economics of the situation. The price of steel castings has increased enormously ; nobody knows where the prices are or what they are going to be tomorrow. This fact is more than ever changing our ideas and driving us towards fabrication. A few years ago I think it was true to say that the fabricated roller-gear frame was more expensive than a steel casting, but today I do not think there is any shadow of doubt that the reverse is true, and that fabricated frames are cheaper than steel castings, and are generally a better job. With present methods of welding one can make a more robust job with a fabricated frame.

With regard to the hydraulic forging presses, it is perhaps a long story to go into now, and it would be better if I wrote to Mr. Owston direct on the subject as it hardly comes within the scope of this paper.

I was interested in and fully agree with Mr. Owston's remarks about flame cutting, because, as I said earlier, I feel that perhaps not too far ahead, there will be a field for that development. I think the information he gives, based on his own experience, should be of interest to all members.

* F. E. Flynn and D. A. MacArthur, *Iron and Steel Engineer*, 1944, vol. 21, Dec., pp. 41–68.

Mr. R. A. Lake (Lancashire Steel Corporation, Ltd.): As a user I should like to say that I entirely disagree with Mr. Pool about the usefulness of 1-hr. ratings for motors for mill auxiliaries. We are speaking about primary-mill auxiliaries, blooming and slabbing mills, presumably, which make a duty cycle several times a minute, and at least once every two minutes, and they do that for 7½ hr. at a time. Of what use is a 1-hr. rating? The manufacturer appears to be wounded in his vanity if he is asked to rate as a mere 20-h.p. C.M.R. a motor which he is accustomed to call 50-h.p., 1-hr. rating. Then why not include after the C.M.R. a peak horse-power figure, as in the case of the main-mill drive? Thus a motor of 50-h.p., 1-hr. rating, might well be 20–150 h.p. We would then not have to write to the manufacturer, when we get into any trouble, asking what the motor will do continuously, and then have to carry out tests to find out what we are demanding of it.

I have made investigations with a very simple device to find out the R.M.S. duty which we require from our blooming-mill auxiliaries. The device consists of a vacuum flask with a spiral of resistance wire in it, a known quantity of water, and a thermometer. It is put in series with the drive, and from the temperature rise in a given time the R.M.S. value of the current supplied can be calculated. These investigations show that the peak horse-power of the auxiliary motors of the mill which I have been investigating is very much greater than that which is ever required. They are made large as they have to dissipate the heat through the frame, because we do not use forced ventilation. In my opinion, if we want to be more economical, we should do so.

I also used this same device with a different type of winding to measure the energy dissipated in the resistance banks of manipulators and screwdown. The figures here were rather startling; 45% of the energy put into the manipulators is completely wasted in the resistance bank and 55% in the case of the screwdown. That seems to support strongly Mr. Grove's plea for Ward-Leonard control of those particular mill auxiliaries.

The only other thing which I think has not been brought out is that once the auxiliary and the motor are there, the actual peak horse-powers required from them are decided by the control gear, unless some mechanical disaster has occurred and the friction load has gone up enormously. The peak horse-powers are those given by the machine during acceleration. The time of operation of the control gear affects the maximum currents, and therefore the maximum torques; it also affects, even with a series motor, the R.M.S. value of the duty cycle. Therefore, within small limits, adjustments to the control gear can enable one with a borderline case to bring the R.M.S. duty cycle within the capacity of the machine.

Mr. **R. L. Willott** (John Summers and Sons, Ltd.): I would like, first, to congratulate the authors upon their nicely provocative presentation of subject matter in both papers. Contributions of this character must inevitably make meetings of the Engineers Group well worth while.

Mr. Franklin mentioned the possibility of substituting for the orthodox screwdown dial a remote-controlled indicator in the operating pulpit itself. Personally, I feel that the operator ought to keep his eye on the mill. To change focus and plane of vision every time a screw setting is made must be physiologically fatiguing during fast rolling. The electrical equipment involved represents an "extra" in initial supply and subsequent maintenance which seems hardly warranted. The orthodox dial, suitably improved along the lines suggested by the author, should meet all reasonable requirements.

Flame cutting *versus* shearing, so far as slab mills are concerned, for reasons other than capital and maintenance expenditure, holds promise. Slab distortion by shears can cause stacking hazards, damage to slab-reheating furnace-charger gear and furnace bottoms, delays on feeder tables, and unnecessary impact loads on table rollers. For subsequent continuous strip-mill reduction, rarely more than four cuts per ingot are necessary at the slabbing mill and these might be made simultaneously with multiple heads. Such an equipment, operating in conjunction with lifting fingers between table rollers, could replace present gauge-head gear. There would be some small extra loss of yield which must be taken into account. Although Mr. Johnson has pointed out very clearly the difficulties of the process, I think that it ought to be actively pursued by the manufacturers.

On the subject of bolts in roller-table drives, we have found some advantage in using high-tensile bolts with good locking arrangements. Ordinary mild-steel bolts stretched and worked loose, involving high maintenance costs, until replaced by better-class material.

Scale removal is briefly mentioned in the paper, and it has already been said this morning that something must be done about it. Unfortunately the all-too-frequent cry in connection with scale removal from primary mills is to the effect that "something ought to be done about it." May I therefore rise to Mr. Franklin's bait and make a plea for certain fundamentals?

Mill scale is not pure scale. Besides being very variable in character and in size (from "plates" to fines), it is mixed with fins, top plates, and other large extraneous swarf, which readily form "beaver-dams" in restricted spaces. If grids are provided to filter-out this heavy swarf, the lodgment hazard is likely to be aggravated. On this score, the most serious restriction ought to be the designed space between breast rollers and work rolls. Everywhere else there should be free fall without lodgment.

Personally, I favour simple hydraulic handling in preference to complicated mechanical conveyors or movable containers. This implies smooth, steep slopes at about 60°, falling into perfectly shaped round channel bottoms. Since concrete surfaces erode rapidly, sides and channel bottoms should be cast-iron faced.

Dribbling, lazy water jets, which are not peculiar to our mill at Shotton, move little. A great volume of water will handle fine scale, but it leaves behind heavy scale "plates" and dam-forming swarf. High-pressure nozzles, on the other hand, will drive all these accumulations along straight, smooth, metal-faced channels. By high pressure I mean, for example, standard ¾-in. L.C.C. fire-hoze nozzles at 100–150 lb./sq. in. For economy they might be operated at definite intervals of 5–15 min.

Directly below the rollers, fore and aft of the mill, there should be a full-width vee channel running the whole length of the tables, with high-pressure jets at the mill and open ends. These would act as feeders to a wider and deeper vee at right-angles and roughly at the middle of each of the mill tables. These main-extraction channels should be flushed by high-pressure jets at the table end, each spilling into a deep scale pit inside or outside the mill building. Notwithstanding the complications of mill beds and foundations, it should be possible to arrange contours within the mill housing to enable high-pressure jets to flush scale, which would otherwise fall below the work rolls, into the feeder channels.

The emptying of scale pits by grabbing into waggons by overhead crane is, I feel, preferable to the use of

skips, boxes, conveyors, and elevators. Labour charges would be appreciably reduced.

To incorporate these features into mill and run-out foundations calls for bold design with adequate depth ; it would be difficult to achieve in established plant. Since existing systems appear to fail by their very niggardliness, appropriate capital provision for new foundations designed as efficient scale channels, as well as machinery supports, might provide a simple but more effective solution.

Mr. **W. W. Franklin** : I would like to say on the question of Selsyn indication that a recently installed blooming mill in this country has both Selsyn indication and the dial. The Selsyn indicator is actually in the control cabin and almost at the operator's feet. The fact is, however, that he never looks at it and invariably watches the dial. I do not think it has any real value on a blooming mill.

With regard to bolts coming loose, it is the usual practice today to provide adequate locking arrangements for the nuts on the bolts, securing the caps on the bearings for the rollers. In the case of line-shaft bearings we now put a clamp with a single bolt in a form of pivot half-way between the clamp point and the rear tail of the clamp so that it overcomes to some extent the possibility of that bolt coming loose. This is indicated in one of the illustrations in the paper.

On the question of scale disposal, I should like to thank Mr. Willott for his suggestions. In recently built installations, scale disposal has been given very close study during the development of the mill design, and the latest practice is in fact on lines similar to those outlined by Mr. Willott. Carefully designed steep-angled flumes are built into the foundations of the mill, main tables, and approach roller gear. The scale is washed down these flumes by periodical flushing with a large volume of water having a head of about 60 ft. and deposited into scale pits for removal by grabs.

I appreciate that this pressure is very much lower than that mentioned by Mr. Willott and agree that higher pressures would be advantageous.

Mr. **W. P. Snedden** (British Timken, Ltd.) : Mr. Franklin made a strong point about roller bearings hammering into their housing. The particular cases to which he referred were associated with drives, not with live rollers. It is a difficult matter, and it is as old as roller bearings themselves, if it is what we think it is. But the whole issue of roller bearings *versus* plain or oil-flooded bearings is surely a matter of common sense and a question of the advantages of the one as opposed to those of the other, and since Mr. Franklin is trying both, that should settle the issue. I have no fear myself : the roller bearing is very much superior in performance, long service, and ultimate cost.

Regarding the capability of taking the loads, I do not know how many strip mills there are in America now, probably about thirty. I think that amongst those thirty mills, you will not find any tables with plain bearings, so that the advocates of plain bearings had better suggest an alteration in practice to the Americans. (Rather they would do so than I.)

As to the amount of expansion that takes place in a live roller, I will admit that with ball bearings and with many other types of bearings approaching the ball-bearing type, you cannot allow for that expansion. With the roller bearing, it is in the nature of the construction of that bearing that it becomes a very simple matter to allow for the expansion.

I realize fully, of course, that there are occasions when a slab is held on the rollers. It may be there some time while the slab-shear man makes up his mind to cut, and it may be there after a cut for as long as 5 min. if transfer to the reheating furnace is held up by conveyor trouble or other causes, and there is considerable heat radiated towards the bearing ; but with a tapered roller bearing you can take care of this by building the necessary end play into the bearing, thereby allowing for expansion of the revolving elements.

I have had no trouble since 1930 with a roller-bearing table—one of the first equipped in England—and I have had another large table working for ten years without any trouble.

With regard to scale, there is a good deal in this problem, and, as has already been suggested by previous speakers, I would advise you to be very careful, because there is not only scale, but also rough jagged ends coming off the ingots. Whatever type the scale pit is, make sure not only that the angles are steep, but that the surface is smooth and hard, otherwise the water pressure behind the scale will never get rid of it when it builds up behind those huge jagged ends which sometimes fall off the ingot.

There is another very important matter in connection with scale pits. Make sure that there is access to them and away from them. Frankly, unless water is more abundant than is, generally speaking, the case around our plants, we are more or less forced to the old steep-angled sides with trucks underneath which can be readily pulled out somewhere beyond the mill. Another very important point is that, when you have come to the crop ends collected on a rotating table, you have got to take the buckets off the rotating table, and it is very wise to see that the same bucket used on a rotating table is easily disposed of on the existing trucks ; otherwise there will be double handling of the crop ends.

Figure A shows a table-roll mounting which is widely used, a 2-row taper roller bearing being used at one end of the roll and a cylindrical roller bearing floating at the other end. In the design shown the bearing adjacent to the bevel gear is mounted direct in the main girder and in a cap bolted to it. The taper roller bearing is clamped on the roll neck through the gear and in the housing by means of two specially designed rings which

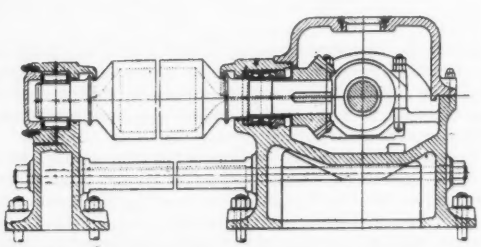


Fig. A—Table-roll mounting

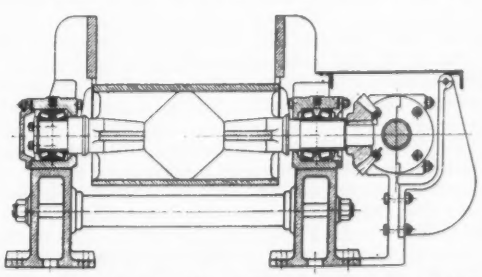


Fig. B—Arrangement for table rolls in approach tables

make it possible to remove the rolls easily and quickly. The inner or right-hand ring is split on the centre-line, the upper half being bolted into the cap, while the lower half rests in the housing. The outer or left-hand ring is made in one piece and is machined with a projection half-way round its circumference. This projection fits into a groove machined in the girder. At the opposite end of the roll a cylindrical bearing is used. The diameter of the inner race of this bearing is made equal to or slightly larger than the diameter of the adjacent shoulder on the roll. This bearing floats to take care of expansion of the roll.

When it is desired to remove a roll from the table the following procedure is followed : The cap at the tapered bearing is removed ; this takes with it the upper half of the split inner ring. The outer ring is rotated 180° to disengage it from the groove in the girder. This allows some freedom in the girder and makes it possible to push the lower half of the split inner ring around until it can be lifted out. With this inner ring out of the way the roll can be slid end-wise sufficiently to enable it to be lifted out.

In Fig. B is shown a typical arrangement for table rolls in approach tables. This design provides a 2-row bearing mounting at the bevel-gear end of the roll, a cup adjusted bearing being mounted in the carriers. At the opposite end of the roll a double-cup *NA*-type bearing is mounted, provision being made for it to float in the bearing box.

CORRESPONDENCE

Mr. **H. Nielsen** (General Electric Co., Ltd., Birmingham) wrote : The present practice of using a 1-hr. or a ½-hr. rating gives the motor manufacturer no information regarding the actual operating conditions, and although he is normally familiar with the general requirements of a given drive, he is often denied access to the data necessary to enable him to calculate the correct thermal rating and peak-load capacity.

As Mr. Grove has stated, it should be possible, knowing the rolling schedule of the mill as a whole, to estimate with reasonable accuracy the duty cycle of each auxiliary unit and thus enable the motor manufacturer to design a motor on the basis of its actual operating duty. This procedure would not necessarily mean a departure from the present range of standardized motors, but merely that the frames could be selected on the basis of their continuous ratings and peak-load capacities instead of by the present practice of selection based on a rather meaningless 1-hr. or ½-hr. rating.

While on this subject I would like to impress upon users or suppliers of auxiliary equipment, particularly of cranes, to so select their gear ratios that standardized speeds can be used in all cases.

We manufacturers find the tendency is to specify speeds higher than the accepted standards, possibly to obtain lower motor prices, but I am sure that it is in the user's best interests that only standardized speeds be employed.

I also agree that it would be preferable to measure the temperature rise by the resistance method, but if this were adopted the allowable figure would have to be increased from 75° C. to approximately 100° C.

On the subject of motor construction, I note that one American manufacturer now proposes to mount the commutator direct on the shaft instead of on a sleeve which also carries the core—the more usual practice introduced to facilitate replacement of a broken shaft.

I would be interested to learn whether the author considers the provision of the sleeve a desirable feature which should be retained.

Referring to roller-table motors, I note the author's preference for group drives, using D.C. variable-voltage motors as against individual A.C. motor drives.

How does Mr. Grove view the recently introduced American practice of employing individual D.C. motor drives, in which groups of motors are controlled on the variable-voltage system ?

On the subject of control, Mr. Grove mentioned Ward-Leonard, 3-field generator, and special exciter systems, but omitted reference to electronic control. Does he not agree that there are applications for this system, particularly where it can be applied as a fine control, in such a manner that the mill may still be operated in the event of a valve failure ?

Is it not likely also that the grid-controlled rectifier will be employed to a greater extent in future with provision, where necessary, for regeneration ?

Referring to cables, there appears to be a tendency in certain quarters to use Pyrotenax in steelworks. Does the author favour this innovation ?

Mr. **W. Craig** (Davy and United Engineering Co., Ltd.) wrote : The comparison of the electrical and hydraulically operated ingot manipulators shown in Figs. 3, 4, and 5 opens up the controversial issue on the relative merits of each medium for the operation of such mechanisms. It is certain that many advances of electrical engineering have made possible the mechanization of certain functions of rolling-mill practice, which formerly were the exclusive field of the muscular giants who in former days were a well-known feature of our steelplants. Nevertheless, a brief study of the sectional drawings shown in Mr. Franklin's paper will prove that for straight-line motions the hydraulic cylinder and ram has much to commend it for efficiency and reliability.

In Fig. 5 the operating unit is shown totally enclosed to prevent the ingress of scale and dust, and with the additional advantage of rams surface-hardened by electrolytic deposition of chrome on the ram surface, this unit can be made a very sound proposition. Another feature is the absolute constant speed throughout the stroke and also the cushioning device which brings the mechanism quietly to rest at the end of the stroke with the entire absence of shock load on the parts. The hydraulic unit here shown should be used in conjunction with a modern air-loaded hydraulic accumulator, which should be situated as near as practicable to the mill to give best results.

With the electric drive through reduction gearing, the motions both for racking and tilting are arrested at the end of the stroke by limit switches, which at best are not definitely reliable, and failures have been known, resulting in vexatious stoppages.

Both these methods for operating manipulators have their adherents and the object of these comments is to suggest that hydraulic operation has many advantages, and in view of the recent improvements in the hydraulic field it should receive careful consideration when a new design of ingot manipulator is under consideration.

Mr. **S. P. Maynard** (Igranic Electric Co., Ltd.) wrote : Mr. Grove has stressed the use of Ward-Leonard equipments on mill-auxiliary drives, especially on those where the duty cycle is mainly acceleration and retardation with very little running time.

From our experience we have found that for drives of this type, direct D.C. application is very much faster for two reasons : (1) The inherent time lag of the generator field on Ward-Leonard equipments, and (2) the initial in-rush current on the direct D.C. equipments, which has a hammer-blow effect that is very useful indeed in unsticking such drives as screwdown, where the oil has

been squeezed out between the nut and the thread, and the stiction in consequence is very high.

One can, of course, somewhat alleviate the first disadvantage of the Ward-Leonard set by means of quick-acting exciters, metadynes, and the like, but only at considerable increase in first cost.

Whilst Mr. Grove deprecates the use of contactor gear on mill equipments, the maintenance costs are very much lower with this type of gear than with Ward-Leonard equipments with their attendant commutators, and these costs are accentuated when metadynes and similar devices are used.

Referring to the layout of control gear, it is noticed that the author prefers totally enclosed equipments, but from experience we have found that totally enclosed contactor panels get little or no maintenance. If open-type panels are situated in motor rooms or special contactor houses, there is very little chance of their being overlooked during routine maintenance and we have had no troubles whatever regarding isolation, as we invariably mount all the equipment for one motor on one set of slates with its own isolator.

Owing to the amount of flying scale, water, etc., to be found in most mills, it is desirable from all points of view that all electrical equipment should be wherever possible mounted external to the mill itself.

Mr. **J. L. Gaskell** (Appleby-Frodingham Steel Company) wrote : Regarding mill-type motors, as the trouble has been taken to indicate the features implied in the title, I consider the reference to the shaft extension at both ends should have been more carefully worded.

In the hope that plant designers will read this paper and the record of the discussion, I do think it should be emphasized that the mill-type motor is designed symmetrical about the fixing-bolt centres so that it can be turned round quickly in the event of the driving end shaft breaking, and that the second shaft extension is *not* provided as a convenient position to accommodate a brake or an auxiliary drive.

If it is desired to specify the limiting temperature rise by the resistance method for acceptance tests, then I suggest the table in B.S.S. 173 for traction motors be used. In this table the resistance rise corresponding to 75° C. thermometer rise is 100° C.

I have experienced some trouble with rubber-insulated cables for the connections to field coils and brush gear on mill-type motors, and cannot see any justification for a motor maker using rubber on a machine sold as class-B insulated. Probably A.V.C. cable is as good for this purpose as any available at present. These internal cables are also not always as securely braced as they might be against movements due to severe current peaks.

I support the authors' suggestion for a standardized range of motors for variable voltage working. On a plant where a substantial measure of motor standardization has been established, the individual design of variable-voltage motors with the necessity of carrying individual spares is a deterrent to their adoption.

With regard to Ward-Leonard control and series control, the author seems to have no good word to say for the simple straightforward series motor for primary auxiliaries;; yet this type has much to commend it, not the least being the ability to standardize a range of, say, 15, 25, 40, 60, 80, and 100 h.p. at 1-hr. rating, which will cover most mill-auxiliary and crane drives.

It is stated that economy in operating cost with Ward-Leonard control is already acknowledged, but I have yet to see data on power consumption and maintenance costs taken on a strictly comparable basis. It would be very interesting if someone who has had the opportunity of making such a comparison would make the data, including data on operation times, generally known. Also, Ward-Leonard control involves much more equipment than plain series control.

No mention has been made of the possibility of using grid-controlled rectifiers for mill auxiliaries. It seems that all the advantages of Ward-Leonard control could be obtained by this means, at the same time substituting static equipment for motor-generator sets with reduction in maintenance costs. There is also the possibility of using the grid-controlled rectifier in conjunction with the series motor with bridge-connected rectifier for the field, as mentioned by Mr. Carnegie, thus permitting the use of a standardized range of half-a-dozen or so sizes of series motors for all applications.

It would be useful if Mr. Lake would give more details of the calorimeter he devised for determination of equivalent continuous ratings of drives ; also would he confirm that in using this device for determination of losses in resistances he had calorimeters connected at the same time in each step ?

I do not understand the authors' criticism of bulk conversion to D.C. Surely the suitability of a general D.C. supply is a function of its adequacy to meet the demands made upon it, and if it were true that a general D.C. system is more susceptible to system interferences than Ward-Leonard, then there could be no justification for using both methods in the same direct line of production.

On the subject of cabling, trenches along machine foundations involve unwieldy covers if they are satisfactorily to withstand the shocks of heavy parts being lowered ungently on them during maintenance work. Concrete-embedded conduits with substantial draw in boxes and an ample number of spare ways have much to commend them. It is primarily a matter of location which system is the more suitable, and probably the best practical solution is a combination of the two.

With regard to earthing systems, I strongly endorse the authors' statement that these should be visible. Earthing systems are usually taken very much for granted once installed, and if out of sight, damage may go undetected for a long time. Earth-electrode tests are easily made, and should be a matter of routine.

On the subject of lighting, it seems to me the authors rather understate the necessity for a high standard of illumination. They even hint on page 276 that it is quite the thing for the illumination in a motor room to be better than in the mill. A high standard of illumination is a necessary step towards ensuring tidiness and good maintenance, and it has been proved in many industrial operations that the standard of lighting has a direct bearing on production. In fact I see no reason to take advantage of the rolling-mills' exemption from the statutory values of illumination for factories.

The Appleby-Frodingham Steel Company's South Melting Shop has gone into operation with mixed tungsten and mercury lighting, giving an illumination of 6–7 foot-candles and the decorations are of the kind for which the author makes his plea. The illumination in the section mills, at present in course of reconstruction, will vary between 8 and 9·5 foot-candles.

The aerials in the roof of the new melting shop would not offend the most artistic eye and have the great virtue of simplicity. We have P.B.J. aerials which have given trouble-free service for over 20 years in melting-shop atmosphere.

Overhead cranes should be regarded as the most dangerous of machines in a steelworks and should not be used for the purpose of lighting maintenance if any other method is practicable. In our roofs of orthodox design, we use hand-railed catwalks in the roof trusses, thus giving access to the lighting independently of cranes.

AUTHORS' WRITTEN REPLIES

Mr. **W. W. Franklin** wrote in reply : Mr. Sneddon suggested I was referring to drives when discussing the question of roller bearings hammering into their housings. This is not so : I was limiting my remarks to roller tables only. The subject of drives is an entirely different matter. The capability of roller bearings taking the loads has never been questioned and I am quite satisfied that the bearings proper are more than adequate for their duty.

I quite agree with Mr. Sneddon that in America many blooming and slabbing mill main tables are roller-bearing mounted throughout, but as I emphasized in the paper, elaborate and costly arrangements are made in American designs to mitigate the hammering effect by ensuring that it affects a readily replaceable item and not the main table frames proper.

With regard to expansion, I quite agree that this can be and is taken care of quite readily with roller bearings and plain bearings, and the methods of achieving this are fully understood by the mill designers.

Mr. **P. F. Grove** wrote in reply : Mr. Nielsen mentioned an American proposal to mount mill-motor commutators direct on the shaft instead of on a sleeve which carries the core, and this may be a means to cheapen construction, perhaps due to less necessity for replacing broken shafts. The sleeve construction is not universal in this country and is not always employed on some of the smaller frame sizes. This is a point on which the motor makers might collaborate so as to agree to a standard in conjunction with the users.

The use of Ward-Leonard control for groups of individual-drive motors would not seem to offer any advantage for primary-mill table-rollers, and because one or two rolls may take all the load, it is difficult to design suitable individual motors in the restricted space available. For lighter run-out tables the conditions are easier.

Electronic control was not included in the paper because more development seems necessary before regenerative working can be applied by these means, and the type of Ward-Leonard control with rotating machines, mentioned in the paper, is more established for reliable working of the drives in question.

It is to be hoped, however, that the possibilities of static equipment in this respect may form the subject for discussion in the near future.

Pyrotenax cable in my experience has not been so successful in steelworks as might have been expected, owing to serious corrosion in some locations and trouble with joints when subjected to shocks or vibration. There have also been unexpected electrical complications when used with contactor-control equipment.

Mr. Maynard criticizes the application of Ward-Leonard control for fast acceleration and short running-time on the grounds of inherent time lag and lack of hammer-blow effect, but the smoothness and flexibility of variable-voltage working seems to be proving itself on primary-mill installations as wasting less time in overrunning and inching. It is not intended in the paper to condemn contactor control so much as to suggest that variable voltage is more widely suited to this interrelated group of drives forming part of a combined production unit, rather like a machine tool on a large scale.

I do not feel that the maintenance of rotating machines is really serious, but the benefits of Ward-Leonard control can be obscured by introducing too many control devices, and the paper suggests that these might be replaced by simpler direct-controller methods as adopted for main-roll drives. With constant-voltage working it is a fact that much power is wasted in resistances, which is supported by Mr. Lake's statement of actual tests.

The auxiliary drives in the present discussion are confined to one type of mill, and the fact that the Ward-Leonard control is being increasingly used on all the latest mills of this type suggests that its advantages are becoming proved in fact. For other auxiliaries in the steel mill plant and on other mills, I have nothing against contactor control.

Dealing with Mr. Maynard's remarks on control panels, I feel there must be something seriously wrong with routine methods of inspection and testing if maintenance depends always on seeing the contactors. While accepting the general preference for open contactor panels in sub-stations and motor houses, I still feel that enclosed equipment is in the general interests of safety.

In answer to Mr. Gaskell, I am glad that he pointed out the significance of interchangeability of shaft-ends for mill-type motors and that the outboard extension should not be restricted by fitting auxiliary equipment or brakes. This might have been brought out in the paper, although the advantages of combining the flexible coupling with the brake drum, from the point of view of saving inertia, is mentioned in a different place. British Standard Specification 173 for traction motors is nearer to the requirements for mill-type motor ratings, but even so is not entirely suitable, because the cooling conditions are rather different on traction service, and many of these machines are enclosed-ventilated. I feel that a new B.S. specification is called for, entirely devoted to mill-type motors, and hope that the manufacturers will bring this about in collaboration with the users.

I do not consider that the plain straightforward series motor is really suitable for the primary-mill auxiliaries. Mr. Carnegie has supported this, and my answer is much the same as to Mr. Maynard, that the proof of variable-voltage working is in its growing use on all the latest primary mills. Comparative working costs would be most useful, and operating engineers could help the makers in providing more of such information.

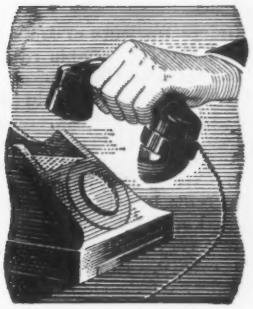
The use of grid-controlled rectifiers has been referred to in answer to Mr. Nielsen, and I am in support of static equipment when it becomes more available for regenerative working.

On the subject of bulk D.C. conversion, I repeat that the auxiliaries in question are part of one production unit and need a specialized integrated control equipment outside the general supply system for auxiliaries.

Perhaps the wording of the paper did not stress the value of lighting sufficiently, but if a step has been taken to draw attention to the necessity of good lighting, my object is partly gained. There is no intention to suggest that lighting in motor rooms should be better than outside in the mill, but more mention might have been made of the actual values that should be attained for better maintenance and greater safety. Mr. Gaskell, however, endorses my opinions in his description of the lighting for his firm's new steelmaking plant, in which some of the suggestions outlined in the paper have been fulfilled. I hope this encouraging and far-sighted example will be followed in many other plants. Catwalks for access to lighting fittings are certainly safer than cranes and I accept entirely this correction to the paper.

In answer to Mr. Lake, I would commend him on his efforts to find out more about actual conditions on auxiliaries by means of practical tests. Such information will be of considerable service to the manufacturers and I hope that Mr. Lake will pursue his investigations further to provide quantitative answers to other suggestions made in the paper.

N E W S



ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE
Annual General Meeting, 1948

The Annual General Meeting of the Institute will be held on Wednesday and Thursday, 5th and 6th May, 1948, in the Lecture Hall of the Royal Institution of Chartered Surveyors, 12, Great George Street, London, S.W.1. The programme of the meeting is as follows:

We nesday, 5th May, 1948

9.45 a.m. to 1.15 p.m.—Morning Session

9.45 A.M. to 10.45 A.M.—Official business: Presentation of the Bessemer Gold Medal, the second Sir Robert Hadfield Medal, and the Williams Prize for 1947. Induction of the President-Elect, Sir Andrew McCance, D.Sc., F.R.S.

10.45 A.M. to 11.30 A.M.—Presidential Address.

11.30 A.M. to 1.15 P.M.—Joint discussion on:

"*Construction and Repair of Open-Hearth Furnaces*," by D. C. Muir. (*December*, 1947).

"*The Design of Open-Hearth Gas Ports*," by M. P. Newby. (*December*, 1947).

"*Installation and Use of Instruments on Open-Hearth Melting Furnaces*," by R. C. Baker. (*September*, 1947).

1.15 P.M. to 2.30 P.M.—Buffet luncheon in the Arbitration Room, Royal Institution of Chartered Surveyors. (Tickets, 6*s*. each, to be applied for in advance).

2.30 p.m. to 5.0 p.m.—Afternoon Session

2.30 P.M. to 3.45 P.M.—Joint discussion on:

"*The Production of Nodular Graphite Structures in Cast Irons*," by H. Morrogh and W. J. Williams. (*March*, 1948).

"*The Carbides in Iron–Carbon–Silicon Alloys and Cast Irons*," by D. Marles. (*April*, 1948).

3.45 P.M. to 5.0 P.M.—Joint discussion on:

"*Abnormal Creep in Carbon Steels*," by J. Glen. (*April*, 1947).

"*The Creep Properties of Molybdenum, Chromium–Molybdenum, and Molybdenum–Vanadium Steels*," by J. Glen. (*January*, 1948).

8.30 p.m.—Third Hatfield Memorial Lecture

Professor Robert F. Mehl (Carnegie Institute of Technology, Pittsburgh, Pa., U.S.A.) will give a lecture on "*The Decomposition of Austenite by Nucleation and Growth Processes*."

Thursday, 6th May, 1948

9.30 a.m. to 12.0 noon—Morning Session

9.30 A.M. to 11.0 A.M.—Joint discussion on:

"*A Micro-Examination of Eight Steels for the Inclusions Sub-Committee*," by J. H. Whiteley. (*September*, 1947).

"*The Study of Segregations and Inclusions in Steel by Micro-Radiography*," by W. Betteridge and R. S. Sharpe. (*February*, 1948).

"*Some Thermodynamical Aspects of the Formation of Inclusions in Mild-Steel Weld Metal*," by E. C. Rollason and E. Bishop. (*February*, 1948).

11.0 A.M. to 12.0 noon—Joint discussion on:

"*A Comparison of Moulds of Standard Composition and of Approximately Ingot Mould Sub-Committee Composition*," by W. L. Kerlie. (*November*, 1947).

"*Mould-Weight/Ingot-Weight Ratio and its Relation to Mould Consumption*," by N. H. Bacon. (*January*, 1948).

Note—The issues of the *Journal* in which the papers appear are given in brackets.

Members' Luncheon

A luncheon for Members will be held on Thursday, 6th May, 1948, at 1.0 P.M. Details will be announced later.

Protection of Steel against Corrosion

A Joint Meeting of The Iron and Steel Institute and the British Iron and Steel Research Association, to discuss several papers dealing with the protection of steel against atmospheric corrosion and marine fouling, will be held at 4, Grosvenor Gardens, London, S.W.1, on Thursday, 17th June, 1948. Full details will be given in the next issue of the *Journal*.

Symposium on Blast-Furnace Practice

The Symposium, which was to have been held on 26th and 27th May, 1948, is now cancelled.

Symposium on Peeling

A meeting to discuss peeling of whiteheart malleable cast iron and the penetration of sulphide in the carburization of steel will be held at the offices of The Iron and Steel Institute, 4, Grosvenor Gardens, London, S.W.1, on Thursday, 8th April, 1948, at 2.0 P.M. Full details of the meeting were published in the February, 1948, issue of the *Journal*.

Indian Institute of Metals

Inaugural Meeting

As announced in the February, 1948, issue of the *Journal*, the inaugural meeting of the Indian Institute of Metals was held on Monday, 29th December, 1947, at the Royal Asiatic Society's Hall, Park Street, Calcutta. Summaries of the inaugural address and the Presidential address are given below.

Inaugural Address

In the course of his inaugural address, Dr. Syama Prasad Mookerjee, Minister for Industry and Supply, said that he had great pleasure in inaugurating the

Indian Institute of Metals. Metallurgists and engineers had a commendable record of work in developing the resources of the country. In a free India members of those professions would have to assume greater responsibilities; for metals, along with power, represented the new age of technology. India had ranked high in metallurgical skill and practices in the Middle Ages; in fact, the art of alloying non-ferrous metals had been known in India long before the Egyptians and the Romans had used such alloys. Consumption per head of population was very low and increased industrialization a national necessity. But the demand for metals in the planned industrial development of the new India would be so enormous that it would be justifiable to say that a new era was about to open in the field of metal production.

Until now the bulk of the mineral resources of India had been exploited solely for export, but if India began industrialization on a worth-while scale, the mineral requirements of the country would assume extensive dimensions and the problem of their conservation and optimum utilization would be one of utmost urgency.

The Minister then outlined other problems that Indian metallurgists would be asked to solve, and the ways in which the Institute would be able to assist in the industrialization of India. He concluded: "I have no doubt in my mind that when the testing time comes, the representatives of the profession gathered here today to inaugurate the Institute will amply prove their mettle."

PRESIDENTIAL ADDRESS

Before Sir Jehangir Ghandy delivered the Presidential address, messages received from various societies and individuals were read out, and representatives of sister societies in other countries were requested to say a few words. Dr. D. P. Antia, Honorary Secretary of the new Institute, represented The Iron and Steel Institute.

In his address, Sir Jehangir Ghandy briefly described the objects of the Institute and referred to the importance of research and the interchange of information. He then reviewed the present position of the non-ferrous metal industry in India which, he said, was almost wholly dependent on imported virgin metals.

Turning to iron and steel, the President deplored the condition of the industry today, occupying as it does a very low place among the iron- and steel-producing nations, in spite of having one of the richest and most extensive deposits of iron ore in the world.

The President then described some of the important advances in the iron and steel industry, particularly during the Second World War, and referred to the Government's decision to establish new steel plants.

In conclusion the President said that the success and usefulness of the Institute depended largely upon the prosperity of the industry. The best brains were required to develop the various metal industries in the country and he hoped that the Indian Institute of Metals would take an effective lead.

Seventy-Five Years Ago

Although developments in the design and construction of blast-furnaces had resulted in considerable savings in fuel consumption, the position was far less satisfactory for the processes concerned with the manufacture of iron in its malleable form. The reverberatory furnace was used almost exclusively for the conversion of pig into wrought iron and even in the best furnaces the heat loss was about 30%. The new Siemens regenerative system, in which the gases were cooled to about 400° F. instead of escaping at about 2000° F., showed no greater direct saving of fuel, but its effective duty was at least twice that of the old type of furnace.

Seventeen years earlier the retiring President, Sir Henry Bessemer, read before the British Association a paper entitled "On the Manufacture of Iron and Steel without Fuel." Needless to say the title provoked considerable comment and no little ridicule. However, the continued perseverance of the inventor and the introduction of manganese into the converter, almost by chance, so improved the process that, in the words of Sir Lowthian Bell, "the invention constituted and will continue to constitute a most important era in the history of the iron trade, both as regards the ingenuity of the apparatus employed, and as regards the opportunity it has afforded the world, for the first time of applying cheap steel in cases where iron had hitherto been exclusively made use of."

In spite of the great advances introduced by the Bessemer converter even greater efficiency was being obtained by the Siemens-Martin process, for which the total fuel consumed did not exceed that employed for driving the machinery, melting the pig, and keeping the converters hot in the Bessemer process.

Before leaving the subject of steel, to speak of labour costs, the President, in his address to the Institute, referred to a proposal by Sir Joseph Whitworth to reduce the gas content of liquid steel by means of extreme compression. Steel so compressed during cooling of the ingot had been found to bear fully double the tensile strain of the best iron made in the country. He also referred to the troubles experienced by the presence of sulphur and phosphorus in pig iron obtained from the Bessemer converter. Many remedies were specified but by the year 1873 no satisfactory solution had been found.

NEWS OF MEMBERS

▶ Mr. R. H. BAULK is now at the Department of Fuel Technology, University of Sheffield.

▶ Wing Commander J. B. R. BROOKE, general manager of the Normanby Park Steelworks, Scunthorpe, of John Lysaght, Ltd., is leaving the company.

▶ Mr. D. L. DAVIES has left the United Steel Companies, Ltd., to take up an appointment with Richard Thomas and Baldwins, Ltd., Panteg Works, Griffithstown, near Pontypool, Mon.

▶ Mr. A. H. DIXON is leaving this country to go to South Africa on behalf of Messrs. Ashmore Benson Pease and Co., Ltd. His address will be c/o Ashmore Benson Pease and Co., Africa (Pty.), Ltd., P.O. Box 8608, 901–905, Jubilee House, 15, Simmonds Street, Johannesburg, South Africa.

▶ Dr. GEORGE DREVER has taken up an appointment with the Walterisation Co., Ltd., in their Research and Development Department, at The Knoll, South Holmwood, Dorking, Surrey.

▶ Mr. JOHN O. EDWARDS is relinquishing his position with the British Aluminium Company to take up an appointment in Ottawa with the Metallurgy Division of the Bureau of Mines.

▶ Mr. GEORGE T. MOTOK has been appointed Director of Research and Development, Champion Rivet Co., Cleveland and East Chicago, Inc.

▶ Mr. H. D. PHILLIPS has changed his address to the Hartford Electric Steel Corporation, Hartford, 6, Conn., U.S.A.

▶ Mr. J. H. M. REID has been transferred from the Research Department, Witton, Birmingham, to the Landore Works, Swansea, of the Imperial Chemical Industries, Ltd., Metals Division.

▶ Mr. W. B. ROWLANDS has joined the Lancashire Steel Corporation, Ltd., Irlam, as assistant blast-furnace manager.

▶ Dr. C. SYKES, F.R.S., has succeeded Mr. T. F. RUSSELL, as President of the Sheffield Metallurgical Association.
▶ Mr. GERALD E. TANNER has left the Appleby-Frodingham Steel Company, where he held the position of assistant plate-mill manager, to take up an appointment as manager of the 32-in. section mill at the Cargo Fleet Iron Co., Ltd., Middlesbrough.
▶ Mr. JOSEPH WALTON, an Assistant Managing Director of Thos. W. Ward, Ltd., Albion Works, Sheffield, has been appointed Chairman and Managing Director of the Darlington Railway Plant and Foundry Co., Ltd.

Corrigendum. Mr. S. H. BROOKES—In the notice on page 258 of the February issue of the *Journal*, concerning Mr. S. H. Brookes, "fuel engineer" should read "a fuel engineer."

CONTRIBUTORS TO THE JOURNAL

H. W. Kirkby, A.Met., F.I.M.—Research metallurgist at the Brown-Firth Research Laboratories, Sheffield. Mr. Kirkby received his early technical education at Sheffield University and was awarded the Associateship in Metallurgy and the Mappin Medal in 1935. Since that date he has been engaged upon metallurgical research at the Brown-Firth Laboratories, where he is at present specializing in high-temperature steels.

J. I. Morley, A.Met., A.I.M.—Member of the staff of the Brown-Firth Research Laboratories. Born in 1917 at Sheffield, Mr. Morley was educated at the Nether Edge Grammar School and at Sheffield University. During the recent war he was attached to the war-time light-alloy foundries of Messrs. Thomas Firth and John Brown, Ltd., as metallurgical adviser. Since the war Mr. Morley has been engaged in the study of austenitic stainless and heat-resisting steels.

Laurence Smith, B.Sc., A.I.M.—Technical Officer in the Metallurgical Section, Imperial Chemical Industries, Ltd., Billingham Division. Mr. Smith was born at Middlesbrough in 1909 and educated at St. Mary's College, Middlesbrough. In 1925 he joined Messrs. Richard Hill and Co., wire manufacturers, as laboratory assistant and transferred to Messrs. Dorman, Long and Co., Ltd., in 1927 as shift chemist. The following year he took up a position with his present firm as laboratory assistant. Mr. Smith obtained an honours degree in metallurgy from London University as an external student, studying at the Constantine Technical College, Middlesbrough, where he is now a part-time lecturer in metallurgy.

K. W. J. Bowen, B.Sc.—Research worker in the Department of Metallurgy, Cambridge University. Mr. Bowen was born in Newport, Monmouthshire, in 1924 and was educated at Newport High School and at University College, Swansea. In 1944 he joined the staff of Imperial Chemical Industries, Ltd., where he remained as an assistant metallurgist until going up to Cambridge in October of last year to undertake research work.

K. W. J. Bowen

L. Smith

H. W. Kirkby

J. I. Morley

G. D. S. MacLellan, M.A., G.I.Mech.E.—University Demonstrator in the Engineering Department, Cambridge, and Fellow and Director of Studies in Engineering, at Pembroke College, Cambridge. Mr. MacLellan obtained his degree in 1942, and for the next two years remained at the University, assisting in teaching in the Engineering Department. He was also engaged in research on wire-drawing dies and lubricants, under Professor E. K. Rideal, F.R.S., with Dr. R. W. Lunt, of Callender's Cable and Construction Co., Ltd. In 1944 he went for two years to the newly formed Research Department of Vickers-Armstrongs, Ltd., Elswick Works, Newcastle-upon-Tyne, where he was concerned with various problems connected with remote power-control systems, and received further practical training. He returned to Cambridge in 1946.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Hardenability Test Charts

The Metallurgy (General) Division of the British Iron and Steel Research Association has arranged for supplies of **Jominy-hardenability** and **isothermal-transformation** test charts to be made available. The Jominy-hardenability test charts are as illustrated in the Symposium on the Hardenability of Steel (*The Iron and Steel Institute, Special Report No. 36*, facing page 24), and the isothermal-transformation test charts have been designed by the Thermal Treatment Sub-Committee. The charts are lithographed on tracing paper and both types may be obtained, price 7*s.* 6*d.* per pad of 50 charts (postage extra), only from Messrs. Pawson and Brailsford, Ltd., Printers and Manufacturing Stationers, Mulberry Street, Sheffield, 1.

Staff Appointment

Mr. J. SAVAGE has been appointed Deputy Head of the Physics Department of the British Iron and Steel Research Association, in addition to his duties as Head of the General Physics Section. Mr. Savage will take over certain administrative duties of the Department.

NEWS OF SCIENCE AND INDUSTRY

The Flow of Ice and Other Solids

A joint meeting between the Institute of Metals, the British Glaciological Society, and the British Rheologists Club is to be held at 4, Grosvenor Gardens, London, S.W.1, on Thursday, 29th April, 1948. The subject to be discussed is "*The Flow of Ice and Other Solids.*" Members of the Institute are cordially invited to attend. Further details of the meeting will be published later.

Canadian Institute of Mining and Metallurgy

50TH ANNIVERSARY

The Jubilee Meeting to commemorate the 50th Anniversary of the incorporation in 1898 of the Canadian Institute of Mining and Metallurgy will coincide with and include the Annual General Meeting for 1948. It will be held in Vancouver from 5th to 8th April, 1948.

Creep in Metals

The Institute of Physics announces that a summer school in theoretical physics, with particular application to creep in metals, will be held in the H. H. Wills Physical Laboratory, University of Bristol, from 2nd to 5th June, 1948. Further particulars and application forms (which must be returned by 15th April, 1948) may be obtained from the Secretary of the Institute of Physics, 47, Belgrave Square, London, S.W.1.

Metallurgical Association of Italy

The Second National Meeting of the Metallurgical Association of Italy (Associasione Italiana di Metallurgia) will take place in Milan from 23rd to 25th April, 1948. Two papers, on "*Corrosion*" and "*The Ageing of Metals*," are to be discussed. Further information may be obtained from the offices of the Association at Via S. Paolo, 10, Milan.

Beilby Memorial Awards

The Administrators of the Sir George Beilby Memorial Fund, representing the Institute of Metals, the Royal Institute of Chemistry, and the Society of Chemical Industry, have decided to make the following awards for 1947: Dr. G. V. Raynor, for his researches on the constitution of alloy systems, and Dr. G. R. Rigby, for his researches on refractory materials.

Situation Vacant

Editorial Assistant required by The Iron and Steel Institute. Details of experience, age, and salary required to the Secretary, 4, Grosvenor Gardens, London, S.W.1.

Sheffield University Gazette

The first issue of the *Sheffield University Gazette*, dated February, 1948, has now been published. The object of the *Gazette* is to issue at short and regular intervals an authoritative picture of the activities of Sheffield University. Copies are obtainable (price 3*d*.) from the Registrar.

First International Powder-Metallurgy Conference

The Steiermark branch of the Association of Austrian Chemists is arranging an International Powder-Metallurgy Conference to be held from 12th to 16th July, 1948, at Graz. Lectures by experts and discussions will provide a comprehensive picture of the position and problems of powder metallurgy and its allied fields, covering scientific, industrial, and economic aspects.

Further information may be obtained from Dr. C. Sykes, F.R.S., Brown-Firth Research Laboratories, Princess Street, Sheffield, or from Mr. M. Littman, Compound Electro Metals, Ltd., 42, Pall Mall, London, S.W.1.

DIARY

23rd March—SHEFFIELD METALLURGICAL ASSOCIATION—"*Some Techniques and Results in Metallurgical Research*," by N. P. Allen—198, West Street, Sheffield, 7.0 P.M.

25th March—MIDLAND METALLURGICAL SOCIETIES—"*The Metallurgy of Alloy-Steel Welding*," by L. F. Denaro—James Watt Institute, Great Charles Street, Birmingham, 6.30 P.M.

1st April—LEEDS METALLURGICAL SOCIETY—"*Controlled Atmospheres*," by Ivor Jenkins—Chemistry Department, Leeds University, 7.0 P.M.

5th April—CLEVELAND INSTITUTION OF ENGINEERS—Discussion on "*Oil-Firing of Open-Hearth Furnaces*," to be opened by G. B. Thomas and F. Kennedy—Cleveland Scientific and Technical Institute, Corporation Road, Middlesbrough, 6.30 P.M.

6th April—SHEFFIELD METALLURGICAL ASSOCIATION—"*Precision Casting*," by H. Evans—198, West Street, Sheffield, 7.0 P.M.

13th April—SHEFFIELD SOCIETY OF ENGINEERS AND METALLURGISTS—"*Thin Films on Metals*," by U. R. Evans—Royal Victoria Station Hotel, Sheffield, 6.15 P.M.

20th April—SHEFFIELD METALLURGICAL ASSOCIATION—"*Some Applications of the Supersonic Frequency Detector in Steelworks Inspection*," by F. Turner—198, West Street, Sheffield, 7.0 P.M.

TRANSLATION SERVICE

(The previous announcement was made in the February, 1948, issue of the *Journal*, page 264.)

TRANSLATIONS AVAILABLE

No. 336 (German). J. KLÄRDING: "The Sintering of Iron Ore with Added Lime." (*Archiv für das Eisenhüttenwesen*, 1939, vol. 12, May, pp. 525–528).

No. 337 (German). G. BULLE: "The Production of Pig Iron from Lean Burdens." (*Stahl und Eisen*, 1947, vol. 66–67, Feb. 27, pp. 69–78).

No. 338 (Swedish). E. BERNHULT: "The Yield Point in Bending and the Stress Distribution in Bars and Tubes in Plastic Bending." (*Jernkontorets Annaler*, 1943, vol. 127, No. 10, pp. 491–533).

No. 339 (German). H. BABLIK and F. GÖTZL: "The Lead-Zinc Galvanizing Process." (*Metallwirtschaft*, 1942, vol. 21, Nov. 27, pp. 718–719). H. BABLIK: "The Formation of Hard Zinc in the Lead-Zinc Galvanizing Process." (*Stahl und Eisen*, 1944, vol. 64, Feb. 24, pp. 120–122).

No. 340 (German). F. EISENSTECKEN and E. H. SCHULTZ: "The Behaviour of Sulphur in the Gas and Sulphur Balance in the Basic Open-Hearth Furnace." (*Stahl und Eisen*, 1932, vol. 52, July 14, pp. 677–686).

CHARGES FOR COPIES OF TRANSLATIONS—For the above translations a charge will be made of 10*s*. for the first copy and 5*s*. each for each additional copy of the same translation. Requests should be accompanied by a remittance. The above translations are not available on loan from the Joint Library.

TRANSLATIONS PREPARED AT MEMBERS' REQUEST—Members requiring translations of foreign papers are invited to communicate with the Secretary, who will ascertain whether the translations can be prepared for inclusion in the series.

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

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MINERAL RESOURCES

The North Staffordshire Coalfields and the Properties of the Seams. J. O'N. Millott. (Journal of the Institute of Fuel, 1947, vol. 21, Dec., pp. 71–79). A detailed description is given of the North Staffordshire coalfields, which comprise four separate coalfields, *viz.*, the Potteries, Cheadle, Shaffalong, and Goldsitch Moss. It has been estimated that there is 140 ft. of coal within 4000 ft. depth, distributed in 30 seams of over 2 ft. thickness. Coking, gas, steam, manufacturing, and house coals are worked, and the annual output has varied between 4 and 7½ million tons during the last 30 years.—G. C. J.

The Structure of the Coal Measures in the Pontardawe-Ammanford Area, South Wales. F. M. Trotter. (Quarterly Journal of the Geological Society of London, 1947, vol. 103, No. 410, pp. 89–133).

The Durham Coalfield. J. Jones. (Year-Book of the Coke-Oven Managers' Association, 1947, pp. 318–331). The coal reserves of Britain are discussed on the basis of data obtained by the Fuel Research Coal Survey, and the Durham coking coals are surveyed and classified. —R. A. R.

Geology of the Ashford Coalfield. F. N. Hanlon. (Journal and Proceedings of the Royal Society of New South Wales, 1947, vol. 81, Part I, pp. 24–33). A detail account is given of the geology of the Ashford coalfield, in Arrawatta County, New South Wales—C. O.

Iron Ores in Bohemia. G. Meska. (Bánsky Obzor, 1947, vol. 1, No. 2–3, pp. 37–42). [In Czech]. The geology of the iron ores of Bohemia is discussed.—R. A. R.

Chrome Ores in France. V. Charrin. (Chimie et Industrie, 1946, vol. 55, Apr., pp. 305–306). French chrome ore deposits are surveyed and mention is also made of some French concessions in Indo-China.—R. F. F.

Molybdenum and Vanadium—Possibility of Ore Deposits in France. V. Charrin. (Chimie et Industrie, 1947, vol. 58, Dec., pp. 608–610). Molybdenum and vanadium resources of the world are briefly discussed, in particular, the potential French resources.—R. F. F.

Tungsten Deposits in France. V. Charrin. (Chimie et Industrie, 1943, vol. 49, Jan., pp. 52–53).

The Iron-Bearing Constituents of Oolitic Minerals of the Longwy Basin and in Particular the Hydrohematites in These Formations. Simonne Caillère and F. Kraut. (Comptes Rendus, 1947, vol. 224, Mar. 31, pp. 1023–1025).—J. C. R.

Iron Ores Resources of the Pyrenees. V. Charrin. (Chimie et Industrie, 1946, vol. 56, Dec., pp. 506–508). The iron ore deposits in the Pyrenees are surveyed. These deposits could be worked again successfully in view of their richness and the abundance of local natural gas which could replace coal in their treatment.—R. F. F.

Spanish Iron Ore. H. J. Becker. (Mining Magazine, 1947, vol. 77, Nov., pp. 279–280). A brief survey is given of the production, home consumption, and export of the Spanish iron ore industry.—R. A. R.

The Coal-Bearing Formations near Stabbarp. G. Troedsson. (Geologiska Föreningens i Stockholm Förhandlingar, 1947, vol. 69, May–Oct., pp. 273–292). [In Swedish]. A description is given of the stratigraphy and rhythmical sedimentation of the Rhaetic and Liassic beds at Stabbarp, an early coal mine near Eslöv, South Sweden.—R. A. R.

Determinations of the Magnetic Susceptibility of Ores and Rocks from Swedish Iron Ore Deposits. S. Werner. (Sveriges Geologiska Undersökning, Series C, 1945, Yearbook 39, No. 5).

Petrographical Investigations of Hungarian Miocene Brown Coal, Especially That of the Borsóder Becken. E. Szádeczky-Kardoss. (Hungarian Palatine Joseph University, Publications of the Department of Mining and Metallurgy, 1944–47, vol. 16, pp. 176–193).

The Nösslacher Coal—Investigations of the Chemical Character of the Coal Resources at Nösslacher Joch (Tyrol). F. Vogt. (Berg- und Hüttenmännische Monatshefte der Montanistischen Hochschule in Leoben, 1947, vol. 92, July–Sept., pp. 117–125).

Ore Supply for the Future. G. W. Hewitt. (Yearbook of the American Iron and Steel Institute, 1947, pp. 336–355). *See* Journ. I and S. I., 1947, vol. 157, Dec., p. 629.

Raw Materials for Iron and Steel Making. H. W. Graham. (Mining and Metallurgy, 1947, vol. 28, Nov., pp. 538–542). Information on the availability, composition, and physical characteristics of iron ores, coal, and limestone, and on the manner of dealing with impurities is presented in broad outline.—R. A. R.

Chromium Resources of the World. N. Demassieux. (Chimie et Industrie, 1946, vol. 55, Jan., pp. 58–64). Statistics of the world production and resources of chromium are given.—R. F. F.

The World Situation on Coating Materials—Lead, Zinc and Tin. C. A. Ilgenfritz. (Yearbook of the American Iron and Steel Institute, 1947, pp. 300–311). *See* Journ. I. and S.I., 1947, vol. 157, Nov., p. 462.

ORES—MINING AND TREATMENT

The Cornelly Limestone Quarry of the Steel Company of Wales, Ltd. (Journal of The Iron and Steel Institute, 1947, vol. 157, Dec., pp. 617–622).

Process Control in Mines and Concentration Plants. S. Mörtsell. (Värmländska Bergsmannaföreningens Annaler, 1946, pp. 105–155). [In Swedish]. The methods of obtaining data relating to quantity, movement, and quality of materials in mines and concentration plants are described and illustrated, and the presentation and application of the data by the management to improve the efficiency of the plant are discussed.—R. A. R.

Tungsten Carbide Tipped Percussion Drill Bits. (British Intelligence Objectives Sub-Committee, 1947, B.I.O.S. Final Report No. 1614 : H.M. Stationery Office).

Hard-Metal Bits for Rock Drilling. E. Ryd. (Jernkontorets Annaler, 1947, vol. 131, No. 9, pp. 373–410). [In Swedish]. An account is given of Swedish experience in the use of tungsten-carbide-tipped rock-drills. Examples showing the difference in drilling speed and wear of forged steel and hard-metal bits are described and illustrated. The nature of the wear is shown to be different in different rocks. The bad results obtained when using drilling machines with too much power are illustrated.—R. A. R.

Grinding and Treatment of Minerals. (British Intelligence Objectives Sub-Committee, 1947, B.I.O.S. Final Report No. 1356 : H.M. Stationery Office). This is a report on visits to German works engaged in grinding manganese, silica, and barytes ; the concentration of lead, zinc, tungsten, and lithium ; and in the manufacture of plant for crushing, pulverizing, and flotation. —R. A. R.

Notes on the Problems of Flotation, Grain-Size, and the Angle of Contact of Floatable Minerals. G. Tarjan. (Hungarian Palatine Joseph University, Publications of the Department of Mining and Metallurgy, 1944–47, vol. 16, pp. 26–37).

A New Method of Beneficiation of Low Grade Iron Ore by the Wiedelmann Washing Tower. (British Intelligence Objectives Sub-Committee, 1947, F.I.A.T. Final Report No. 869, Supplement No. 1 : H.M. Stationery Office). This supplementary report contains a drawing of the 1000-ton capacity ore-washing tower developed by Wiedelmann, the drawing in the initial report being incomplete. (*See* Journ. I. and S.I., 1947, vol. 156, May, p. 127).—R. A. R.

FUEL—PREPARATION, PROPERTIES, AND USES

Fuel Efficiency in the Iron and Steel Industries. G. Pirou. (Mémoires de la Société des Ingénieurs Civils de France, 1947, vol. 100, Jan.-Feb., pp. 49–56). The author discusses the sources of heat losses and examines the causes of the inefficient use of fuel. Some methods of effecting economies with existing plant are mentioned. —J. C. R.

Fuel Economies Possible in Iron and Steel Production. Durand and Malcor. (Mémoires de la Société des Ingénieurs Civils de France, 1947, vol. 100, Jan.-Feb., pp. 57–69). After reviewing the consumption of fuel in coke ovens, blast-furnaces, and open-hearth, electric, and reheating furnaces, the authors consider what economies are possible and how they can be effected. —J. C. R.

Reactivity of Solid Fuels. H. Guerin. (Chimie et Industrie, 1943, vol. 49, Apr. 15, pp. 195–201 ; 1944, vol. 51, Feb. 15, pp. 24–26). The reactivity of fuels with carbon dioxide, oxygen, and water vapour is defined and methods of determining it are given.—R. F. F.

Comparison of Continuous Recuperators and Siemens Heat Regenerators for Gas Retorts and Coke Ovens. J. H. Grandval. (Chaleur et Industrie, 1945, vol. 26, June, pp. 71–74 ; July pp. 94–100 ; Aug., pp. 115–119 ; Sept., pp. 150–152). A detailed account is presented of the use and respective advantages of recuperators and regenerators for gas retorts and coke-ovens.—J. C. R.

Contribution to the Determination of Fusibility of Ash : Researches on the Temperature of Clinker Formation. E. Rousseau and J. Delorme. (Chimie et Industrie, 1945, vol. 54, Nov., pp. 302–314). The viscosity curve of fuels as a function of temperature has an inflection which shows the temperature at which clinker is produced. —R. F. F.

Automatic Control Applied to Modern High-Pressure Boilers. Ll. Young. (Journal of the Institution of Electrical Engineers, 1947, vol. 94, Part IIA, No. 1, pp. 66–78). The paper describes an air-operated system of automatic control for high-pressure boilers.—R. A. R.

Technical Report on the Ruhr Coalfeld. Vol. III, Appendix No. 27—Utilisation of Low Grade Fuels in Steam Generating Plants. W. Vogel. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 394 : H. M. Stationery Office). A translation is given of a lecture by Dr. W. Vogel to the Second Conference of Experts Specializing in the Construction and Management of Steam Generating Plants, in 1941. The economics of the use of middlings from coal washeries for the raising of steam are discussed, and suitable grates and boilers are described.—C. O.

The Heat and Mass Flow Analyzer—A Tool for Heat Research. V. Paschkis. (Metal Progress, 1947, vol. 52, Nov., pp. 813–818). The principle of the calculating machine known as the heat and mass flow analyser is simply explained. A short account is given of the installation at Columbia University, and of the type of industrial problem which has been solved by it.—C. O.

Coal Preparation. W. Scholes. (Year-Book of the Coke-Oven Managers' Association, 1947, pp. 285–295). A description is given of a new heavy-liquid system of coal cleaning employed at the Derwenthaugh coke-works.—R. A. R.

Notes on Coal Preparation. S. Lynch. (Institute of Fuel, 1947, Preprint). The advantages and problems of central depots for the cleaning of coal are discussed. Typical dense-media processes are considered and two of the later developments, the Ridley-Scholes process and the Dutch State Mines fine-shale system, both of which utilize relatively stable media, are described. The advantages of automatic control of the degree of separation are emphasized.—C. O.

The Gasification of Coal Dust by the Koppers-Totzek Method. F. Totzek. (Stahl und Eisen, 1947, vol. 66–67, Oct. 9, p. 363). The theory and practice underlying the development of the Koppers-Totzek gas-producer are explained. In this producer brown-coal and bituminous-coal dust, and even coke dust, are gasified by an air-steam or oxygen-steam mixture preheated to about 1200° C. The properties of the gas produced, in particular the concentration (up to 95%) of $CO+H_2$, the ease of control of the CO/H_2 ratio, the temperature at which it leaves the producer, and its calorific value (2000–2400 kg.cal/cu.m.), all indicate its suitability for reducing ores, especially for the production of sponge iron. —R. A. R.

Recent Literature on Pulverised Coal Burners. G. W. C. Allan. (Monthly Bulletin of the British Coal Utilisation Research Association, 1947, vol. 11, Sept. pp. 337–348). A review is made of published literature on the combustion of pulverized fuel and developments in the design of pulverized-coal burners. The constructional details are shown of the St. Jasques, the L. V. Andrews and Riley Stoker Corporation and the Lorenzen burners.—R. E.

Pulverised Fuel in Industry. T. Smeaton. (Fuel Economy Review, 1947, Nov., pp. 31–35, 39). Data are given to show that the pulverized-fuel firing of boilers is more efficient than stoker-firing under similar conditions. The application of pulverized-fuel firing to water-tube and shell-type boilers, rotary kilns, and metallurgical furnaces is briefly discussed.—C. O.

Examination of Some Coking Coals of the Central Provinces. P. S. Mene and R. K. Pande. (Quarterly Journal of the Geological, Mining and Metallurgical Society of India, 1947, vol. 19, June, pp. 37–40).

Carbonization of Coal Sprayed with Oil. P. C. Mayfield. (Yearbook of the American Iron and Steel Institute, 1947, pp. 405–414). *See* Journ. I. and S. I., 1947, vol. 157, Nov., p. 463.

Carbonising Coal and Breeze Blends. J. Roberts. (Coke and Gas, 1947, vol. 9, Nov., pp. 337–340). An old proposal to manufacture a smokeless fuel for domestic use by blending coking coal with coke breeze is discussed. One object of this is to maintain continuity of operation of coke-ovens in the north-east of England, and thus offset fluctuating demands for furnace and foundry coke. The disadvantages of fine-crushing of the breeze are pointed out and the properties of the coke produced are critically studied.—R. A. R.

War-Time Experience with a Silica Coke-Oven Battery. W. A. P. Hoskin. (Year-Book of the Coke-Oven Managers' Association, 1947, pp. 303–317). The methods by which repairs to the coke ovens at Worsborough were carried out under war-time conditions are described.—R. A. R.

Safety Device for the Alignment of Ram and Coke Guide Machines. C. R. Plant. (Year-Book of the Coke-Oven Managers' Association, 1947, pp. 241–245).—R. A. R.

The Sikfors Bruk Carbonization Plant. O. Stenberg. (Värmländska Bergsmannaföreningens Annaler, 1946, pp. 157–182). [In Swedish]. A detailed description is given of the wood carbonizing plant at Sikfors Bruk which was built in 1942 to carbonize about 120 cu. m. of wood per day (24 hr.)—R. A. R.

Some Aspects of Benzole Distillation and Pure Products Manufacture. W. J. Chadder and H. M. Spiers. (Year-Book of the Coke-Oven Managers' Association, 1947, pp. 246–284). Some practical features of benzole distillation and pure products recovery are discussed under the following headings: (*a*) Removal of carbon disulphide by distillation; (*b*) reduction of the amount of intermediates in batch distillation; (*c*) continuous distillation of low-gravity benzole; (*d*) production of low-gravity nitration toluole from low-gravity benzole; (*e*) production of high-gravity nitration toluole from low-gravity benzole by azeotropic distillation and other means; and (*f*) recovery of miscellaneous products from benzole—R. A. R.

Gasification of Solid Fuel with Steam-Oxygen Blast. A. F. Ivanov. (Kislorod, 1947, No. 4, pp. 46–49). [In Russian]. A brief account, based on information from British, American, and Canadian technical publications, of the use of steam-oxygen blast for the production of water-gas in Germany, Canada, and Holland is given. —S. K.

Complete Gasification of Fuels by the Koppers Process. J. Barral. (Chimie et Industrie, 1947, vol. 57, May, pp. 441–443). The Koppers process is explained and its application to French requirements discussed.—R. F. F.

Conversion of Water Gas to Hydrogen. Elimination of Carbon Dioxide from the Converted Gas. C. Berthelot. (Chimie et Industrie, 1943, vol. 49, June 15, pp. 313–315). A method is given for producing hydrogen at 20 atm. pressure by the water-gas reaction.—R. F. F.

Kinetics of the Formation of Water Gas in Gas Works Retorts. H. Cassan. (XXe Congrès de Chimie Industrielle: Chimie et Industrie, 1947, vol. 58, Aug., pp. 127–134). The kinetic theory of reversible heterogeneous reactions leading to the relation between rate of flow of the gaseous phase in contact with the coke, the temperature, and quantity of heat obtained by the endothermic reaction, is discussed.—R. F. F.

Production of Hydrogen/Carbon-Monoxide Synthesis Gas from Coke-Oven Gas. (Coke and Gas, 1947, vol. 9, Nov., pp. 346–349). German methods of producing synthesis gas containing hydrogen and carbon monoxide in predetermined quantities from coke-oven gas by conversion of methane and other hydrocarbon gases are reviewed.—R. A. R.

Experiments to Improve Coke Strength. C. W. Stahl. (Yearbook of the American Iron and Steel Institute, 1947, pp. 355–379). *See* Journ. I. and S.I., 1947, vol. 157, Nov., p. 463.

Storage of Coke-Oven Gas in Sandstone Strata. J. R. Bircher. (Chemical Engineering Progress, 1947, vol. 43, Sept., pp. 453–466). Problems connected with the storage of coke-oven gas in exhausted natural-gas sandstone strata are considered. Certain components in the gas lead to the formation of "vapour-phase gum" which is deposited in valves and regulators, or in the pores of rock if stored underground. A process is described for treating the gas so that the maximum amount of gum is formed at the compressing and treating station where it can be removed before the gas enters the sandstone strata.—R. A. R.

Fuels for Gas Producers. A. T. Grisenthwaite. (Fuel Economy Review, 1947, vol. 26, Nov., pp. 45–48). The effects of the grading, caking and swelling properties, and composition of fuels on their efficiency in the gas producer are briefly discussed. The operating variables to be controlled to obtain optimum efficiency are enumerated.—C. O.

Use of Oxygenated Air for the Combustion of Blast-Furnace Gas. M. Steffes. (Chaleur et Industrie, 1946, vol. 27, Mar., pp. 69–72). This is a mathematical study

of the increase in combustion temperature with increase in oxygen content of the air. With pure oxygen a theoretical combustion temperature of 2500° C. could be reached and in practice a temperature of 2000° C. could be attained.—J. C. R.

Gaseous and Liquid Fuels in Iron and Steel Works—Engineering Aspects of Distribution and Utilization. J. B. R. Brooke and J. S. Bryan. (Journal of The Iron and Steel Institute, 1948, vol. 158, Jan., pp. 111–124).

Fuel Oil: Some of Its Industrial Uses and Developments in the U.K. N. L. Hudson. (Fuel Economy Review, 1947, vol. 26, Nov., pp. 15–19) Recent developments in the use of oil as a fuel in the steel, ceramic, fishing, farming, and railway industries are briefly reviewed.—C. O.

Use of Liquid Fuel in Open-Hearth Furnaces. (Iron and Coal Trades Review, 1948, vol. 156, Jan. 2, pp. 24–25). A brief account is given of the annual general meeting of the Sheffield Society of Engineers and Metallurgists, at which members of the Sheffield Metallurgical Association and of The Iron and Steel Institute were present. Two papers on the use of liquid fuel in open-hearth furnaces were read, one entitled "The Application of Oil Fuel to Open-Hearth Furnaces," by H. C. White, and the other "Instrumentation and Control of Oil-Fired Open-Hearth Furnaces," by F. A. Gray.—J. R.

REFRACTORY MATERIALS

Stabilised Dolomite. W. De Keyser. (Revue Universelle des Mines, 1947, Series 9, vol. 3, No. 12, pp. 605–609). The manufacture of stabilized dolomite in rotary kilns and the use of dolomite bricks as a substitute for magnesite bricks are discussed.—R. F. F.

Stabilized-Dolomite Bricks. K. Endell. (Stahl und Eisen, 1947, vol. 66–67, Aug. 14, pp. 290–293). After a short review of American and Russian work on stabilized-dolomite refractory bricks with special reference to the stabilizing of the calcium orthosilicate, some mineralogical, chemical, and X-ray studies of three German experimental stabilized dolomites are described.—R. A. R.

Some Experiments on the Permeability of Bricks. W. T. Grey Davies. (Year-Book of the Coke-Oven Managers' Association, 1947, pp. 296–302). The results of tests in which the quantity of gas which passed through coke-oven silica bricks under different testing conditions are presented and discussed, and the methods of testing are described.—R. A. R.

Special Refractories—Metal Melting. W. H. Henson. (American Foundryman, 1947, vol. 11, May, pp. 64–70). *See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 291.

The Development of Basic Insulating Bricks. J. H. Chesters, T. W. Howie, and T. R. Lynam. (Transactions of the British Ceramic Society, 1947, vol. 46, Nov., pp. 349–370). A detailed account is given of tests made with the object of developing a brick suitable for the all-basic furnace roof. Most of the work was done on chrome-magnesite and serpentine-magnesite, although spinel and zircon were also tried. Porosity was obtained by the addition of foam, combustible materials, naphthalene, or minerals such as magnesite, which lose weight on firing. Satisfactory bricks were made in the laboratory, but there are many obstacles to commercial production. The best results were obtained with a chrome-magnesite batch, to which sufficient raw magnesite was added to give 30% MgO in the product, and with serpentine-magnesite batches made from calcined serpentine, raw magnesite, and sawdust.—C. O.

Refractories Used in Metallurgy in the U.S.A. Y. Letort. (Société Française de Métallurgie: Revue de Métallurgie, 1946, vol. 43, July–Aug., pp. 208–213). Current American practice in the manufacture and use of refractories is surveyed.—R. F. F.

Production of Fused Silica. B. A. Rogers, W. J. Kroll, and H. P. Holmes. (Electrochemical Society, 1947, Preprint No. 92-29). Methods of making silica tubes and other silica equipment for laboratories are outlined, and experimental results on the production of silica lumps up to 40 lb. in graphite-resistor and electric-arc furnaces are described.—R. A. R.

The Determination of the Porosity of Refractory Materials. M. Lepingle. (Chaleur et Industrie, 1945, vol. 26, July, pp. 101–106). After reviewing the various methods in use for determining porosity of refractory materials, the author outlines a shorter method which gives accurate results.—J. C. R.

Properties, Characteristics and Behaviour in Service of Refractory Materials. Y. Letort. (Fonderie, 1946, Mar., pp. 87–98). After classifying refractory materials according to their chemical and mineralogical nature, the author considers their resistance to heat, mechanical resistance to heat and cold, and resistance to thermal shocks and chemical corrosion.—J. C. R.

Physical Changes Occurring during Re-Pressing of Fire-Clay Refractories. J. O. Everhart. (Journal of the American Ceramic Society, 1947, vol. 30, Nov. 1, pp. 345–348). Nearly all stiff-mud fireclay refractories are extruded and then re-pressed in machines to bring them accurately to size. When there is any appreciable difference in size between the extruded blanks and the re-pressed piece, much of the density is lost, and this loss is unaffected by the grain-size and moisture content, but is proportional to the distortion necessary to form the blank into the desired shape.—R. A. R.

Reliability of "Workability Index" of Fire-Clay Plastic Refractories. R. A. Heindl and W. L. Pendergast. (Journal of the American Ceramic Society, 1947, vol. 30, Nov. 1, pp. 329–334). The reliability of the A.S.T.M. method for determining the facility with which plastic refractory material can be rammed (*i.e.*, the workability index) is discussed.—R. A. R.

The Development of Refractories for High-Temperature Industrial Processes. A. Hilliard and J. H. McKee. (Monthly Bulletin of the British Coal Utilisation Research Association, 1947, vol. 11, Nov., pp. 457–468). This is a review of the published literature on the manufacture and properties of high-temperature refractories and insulating materials. The alumina–silica diagram is shown and analyses of typical refractory bricks are tabulated. Tables are also included giving the melting points of refractory oxides, silicates, carbides, nitrides, and borides.—R. E.

Magnesite Coatings for Ladles Transporting Pig Iron between the Mixer and Converters. Recht. (Revue de Métallurgie, 1946, vol. 43, July–Aug., p. 234). Magnesite linings in ladles will lengthen their life to the order of 30,000 tons of metal transported. Whilst in operation these ladles must not be subjected to wide variations in temperature.—R. F. F.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

New Blast-Furnace Plant at Colvilles, Limited. (Iron and Coal Trades Review, 1947, vol. 155, Nov. 7, pp. 901–904). Details are given of a new blast-furnace and its auxiliary equipment, installed at the Clyde Iron Works plant of Messrs. Colvilles, Ltd. It is anticipated that the new furnace, the hearth diameter of which is 20 ft., will be capable of producing 4500 tons of iron per week.—J. R.

Is the Production of Iron from Iron Ores by Reduction with Calcium Carbide Possible ? V. Uxa. (Hutnické Listy, 1946, vol. 1, No. 5, pp. 108–109 ; No. 6, pp. 133–137). [In Czech]. The theory of the production of pig iron using calcium carbide as a reducing agent is examined. It is considered that the process can be more economical than the Swedish electric blast-furnace if the carbide is manufactured by hydro-electric power in spring during the flood-water period, and it can be used to make iron when surplus electric power is not available. The Vareš hematite in Yugoslavia would be a suitable ore.—R. A. R.

Reduction of Iron Oxides in the Presence of Foreign Matter. F. Olmer. (Revue de Métallurgie, 1941, vol. 38, May, pp. 129–134). This is a summary of a thesis on the reduction of iron oxides by hydrogen and carbon monoxide. The apparatus and methods used are described, but full results are not given.—R. F. F.

The Krupp-Renn Plant at Salzgitter. (British Intelligence Objectives Sub-Committee, 1947, F.I.A.T. Final Report No. 727 : H.M. Stationery Office). A short history of the Hermann Göring Works at Salzgitter is followed by a summary of the methods used there to prepare the ores. A detailed account is then given of the Krupp-Renn process for working up ores into a product containing 95% of iron.—R. A. R.

Thermal Balance of Cowper Stoves. (Métallurgie, 1947, vol. 79, Oct., pp. 11–16). An account is given of an investigation into the thermal efficiency of Cowper stoves.—J. C. R.

The Development of the Blast-Furnace Profile in Different Countries. P. Wolf. (Stahl und Eisen, 1947, vol. 66–67, Dec. 4, pp. 411–416). The development of blast-furnace profiles in the industrial countries is reviewed. The conclusions drawn include the following : (1) The hearth diameter is independent of the quality of the coke ; (2) bosh angles have increased from 35° in 1825 to 85° in 1925, and there are now one or two furnaces with no bosh ; (3) the shaft diameter depends on the charging scheme, the formation of flue dust, and the rate of gas flow ; (4) the average load on the hearth is about 1000 kg./sq. m./hr. for nearly all furnaces ; and (5) the accurate determination of the shaft- and hearth-diameter ratio depends upon the difference between the coke saved in a good charging scheme and the cost of beneficiating flue dust.—R. A. R.

A Design for Blast Furnace Hearths. W. S. Unger. (Yearbook of the American Iron and Steel Institute, 1947, pp. 95–112). *See* Journ. I. and S.I., 1947, vol. 157, Nov., p. 465.

Blast Furnace Bell Development. T. A. Kennedy. (Yearbook of the American Iron and Steel Institute, 1947, pp. 113–124). *See* Journ. I. and S.I., 1947, vol. 157, Nov., p. 465.

Ironmaking at Appleby-Frodingham. G. D. Elliot. (Revue de Métallurgie, 1946, vol. 43, Mar.–Apr., pp. 69–83 ; May–June, pp. 169–179). This is an abridged translation of Special Report No. 30 of The Iron and Steel Institute.—R. F. F.

Utilization of Oxygen in the German Iron and Steel Industry. (British Intelligence Objectives Sub-Committee, 1947, F.I.A.T. Final Report No. 1203 : H.M. Stationery Office). An account is given of German developments in the use of oxygen-enriched blast in blast furnaces and basic converters. Of great interest is the low-shaft blast-furnace (19 ft. high) at Trostberg, Bavaria, built to make use of the oxygen produced as a by-product at the nitrogen plant of Suddeutsche Kalkstickstoff Werke. Details of the successful production of pig iron and ferrochromium, and the economic advantages of the plant are given.—R. A. R.

Operation of the Iron Blast Furnace at High Pressure. J. H. Slater. (Yearbook of The American Iron and Steel Institute, 1947, pp. 125–200 : Blast Furnace and Steel Plant, 1947, vol. 35, Sept., pp. 1083–1090, 1107–1108, 1147 ; Oct., pp. 1213–1218). **High Pressure Operation.** J. H. Slater. (Iron and Steel, 1947, vol. 20, Dec., pp. 653–657 ; 1948, vol. 21, Jan., pp. 15–17). *See* Journ. I. and S.I., 1947, vol. 157, Sept., p. 141.

The Desulphurization of Metallurgical Coke. R. Stumper and N. Stoll. (Chaleur et Industrie, 1945, vol. 26, Dec., pp. 219–225). An investigation into the desulphurization of coke using the Galoczy process is described. The following factors were studied in order to determine the optimum conditions : Presence of iron ore ; granulation of the coke/Minette-ore charge ; reaction temperature ; quantity of steam ; rate of gas flow in blast-furnaces ; the period of the reaction. The investigation was carried out by laboratory tests adapted to blast-furnace conditions. The claims made for the process were only very incompletely realized. —J. C. R.

Economic Aspects of Modern Blast-Furnace Practice. J. Miles and G. L. Thomas. (Association des Ingénieurs : Iron and Coal Trades Review, 1947, vol. 155, Nov. 28, pp. 1041–1047). Practical and economic aspects of modern ore-crushing, screening, bedding, and sintering plant are discussed. The importance of slag composition in blast-furnace operation is emphasized, and the value and application of slag-viscosity diagrams are outlined. In view of the state of calcareous Minette ore reserves, the advisability of introducing acid burdening in Minette-ore practice is considered, and comparative data for acid- and basic-burdening practices are given.—J. R.

Influence of the Preparation of Burdens on the Profile of Blast-Furnaces Working Lorraine Minettes. R. Warzee. (Revue de Métallurgie, 1945, vol. 42, Apr., pp. 97–104). In order to achieve the full benefits of pre-treatment of the blast-furnace burden, the profile must be properly designed. On the basis of an analysis of the lines of existing furnaces smelting minette ores, a new and improved profile is suggested.—R. F. F.

Comparison of the Consumption of Coke in the Blast-Furnace. C. G. Thibaut. (Revue de Métallurgie, 1944, vol. 41, Nov., pp. 369–377 ; Dec., pp. 409–430). The published work on various investigations of factors affecting consumption in the blast-furnace is analysed. A bibliography of 120 references is appended.—R. F. F.

Factors Affecting the Coke Consumption in the Blast-Furnaces in the Briey Region. M. Brun. (Revue de Métallurgie, 1945, vol. 42, Sept., pp. 273–285 ; Oct., pp. 308–320 ; Nov., pp. 347–358 ; Dec., pp. 393–401). In order to economize coke, the author studied various factors affecting the consumption of coke in the blast-furnace. These factors include : quality of coke, chemical composition of minerals and metallic additions in the burden, quality of products obtained, temperature of blast and yield of charges, insulation of hot-blast main, humidity of blast, blast-furnace profile and hearth diameter, rate of stock descent, stoppages, amount of pig lost during casting, and evenness of distribution of charge.—R. F. F.

The Possibilities of Influencing the Oxidation Zone of the Blast-Furnace. (Stahl und Eisen, 1947, vol. 66–67, Aug. 14, pp. 277–284). The purpose of the investigations described was to study methods of increasing the oxidation zone in a blast-furnace and to determine whether this would increase the effective hearth area and output. The blast-furnace used for the trials had a hearth diameter of 6·5 m., an effective volume of 818 cu. m., and 10 tuyeres. The effects of increasing the blast pressure and changing the shape of the tuyeres were studied

by taking gas samples from the hearth, bosh, and at 2·5 m. below the stockline. Curves showing the positions of equal oxygen and equal CO_2 contents in horizontal and vertical sections of the furnace were constructed and are presented. The depths of the oxidation zone from the tuyeres towards the centre increased linearly with the blast pressure and the zone could be greatly increased by fitting high-pressure tuyeres in conjunction with suitable low-pressure tuyeres; better control of the flow of gas through the furnace was also obtained. The optimum contour of the oxidation zone for steady operation and high production is an annular area of small inside diameter. In the trials increases of up to 30·4% in production with a decrease in the coke rate of 6·1% were obtained.—R. A. R.

Relationship between Blast-Furnace Burden and Fuel Economy in Iron and Steel Works. H. Schumacher. (Stahl und Eisen, 1947, vol. 66–67, Nov. 6, pp. 375–379). A practical example of the energy balance for an integrated iron and steel works is examined and data are presented on the relation between the surplus heat from the blast-furnace and the heat requirements of the steel plant and rolling mills. Under conditions of low production the coke rate at the blast-furnaces is higher; the effect of this on the net heat consumption per ton of steel is pointed out. The quantities of slag produced from German ores and well-known foreign ores are compared. Having regard to the present and future shortage of fuel, the necessary improvement to the blast-furnace burden can only be attained by the import of richer ores.—R. A. R.

Concentration of Manganese from Liquid Spiegeleisen in a Sulphide-Oxide Slag. H. Löfquist. (Jernkontorets Annaler, 1947, vol. 131, No. 11, pp. 493–517). [In Swedish]. The paper describes developments in the author's method of enriching spiegel produced from mixtures of pig iron and ferromanganese. (For details of the original method *see* Journ. I. and S.I., 1943, No. I, p. 42A). The synthetic slags are now formed more rapidly and efficiently by blowing in the slag formers containing sulphur and oxygen at the bottom of the molten spiegel so as to increase the reaction surface. The tests were made with a 230-kg. melt in a 50-kW. Rennertelt furnace. The slag formers tried were sulphur dioxide with and without pyrites concentrate, pyrites concentrate blown in with air, and pyrites + magnetite concentrate blown in with air and with nitrogen. Slags of full equilibrium composition were obtained with sulphur dioxide + pyrites. For practical reasons it was best to blow in pyrites concentrate with a controlled amount of air, in which case the surplus nitrogen protected the slag surface from oxidation of the sulphur. This method was found to produce, with high recoveries of manganese and sulphur, slags containing Mn 60–65%, Fe 3–5%, SiO_2 3%, and S 16–18%, which were fluid at 1350–1400° C. A heat balance is presented and it indicates that such a process could be carried out in a converter by its own reaction heat.—R. A. R.

Blast-Furnace Output per Unit Hearth Area. (Stahl und Eisen, 1947, vol. 66–67, Dec. 4, pp. 425–427). As a unit for considering the outputs of blast-furnaces the coke throughput per square metre of hearth per hour is selected and comparisons are made between the outputs on German blast-furnaces in different districts from 1942 to 1947. These rates are also compared with data from British ironworks.—R. A. R.

Study on the Breaking-Up of Iron Ores in the Blast-Furnace and Its Effects. J. Fortado. (Revue de Métallurgie, 1946, vol. 43, July–Aug., pp. 219–228). The disintegration of lumps of French iron ores was investigated in the laboratory in an apparatus simulating blast-furnace conditions. The apparatus and the tests used are described and the results obtained on a number of ores, in carefully graded samples, noted.—R. F. F.

A Method of Estimating Blast Furnace Production and Coke Consumption. W. E. Marshall. (Yearbook of the American Iron and Steel Institute, 1947, pp. 379–404). *See* Journ. I. and S.I., 1947, vol. 157, Nov., p. 465.

PRODUCTION OF STEEL

Multiple Correlation Applied to Steel Plant Problems. W. T. Rogers. (American Society for Metals, 1948, Preprint No. 27). This paper explains the application of multiple correlation methods to four different types of problems encountered in a large steel plant.—R. A. R.

Selection and Application of Statistical Methods to Steel Plant Processing Problems. E. L. Robinson and L. G. Ekholm. (Yearbook of the American Iron and Steel Institute, 1947, pp. 539–557). *See* Journ. I. and S.I., 1947, vol. 157, Nov., p. 467.

Metallurgical Investigations on the Working of the Basic-Bessemer Process with Oxygen-Enriched Blast. W. Eilender and W. Roeser. (Iron and Steel Institute, 1947, Translation Series, No. 326). This is an English translation of a paper which appeared in Stahl und Eisen, 1939, vol. 59, Sept. 21, pp. 1057–1067 (*see* Journ. I. and S.I., 1940, No I, p. 79A).—R. A. R.

Open-Hearth Design—A Plea for the Revival of the Terni Furnace. V. Ferri. (Iron and Steel, 1947, vol. 20, Dec., pp. 649–651, 657). The Terni open-hearth furnace aroused considerable interest on its inception some fifteen years ago but is now almost forgotten. The furnace simply and successfully solved one of the fundamental problems of open-hearth steelmaking and gave striking results as regards melting rates, outputs, and fuel consumption. Conversion of the ordinary open-hearth to the Terni design is simple and many such conversions were made, but the general experience was that the benefits obtained lasted for only a few weeks and seemed invariably to have been achieved at the expense of furnace life; in the final analysis the advantages were doubtful, or even negative. A description of the furnace and its operation is given, and it is suggested that with the utilization of present-day refractories and some modification to the original construction, a revival of the design is worthy of consideration.—J. R.

The Design of Open-Hearth Gas Ports. M. P. Newby. (Journal of the Iron and Steel Institute, 1947, vol. 157, Dec., pp. 601–608).

Some Notes on German Open Hearth Furnace Design and Operation. (British Intelligence Objectives Sub-Committee, 1947, B.I.O.S. Final Report No. 1667: H.M. Stationery Office). This Report consists mainly of observations on German open-hearth furnace design and operation, and discussions on the rolling and annealing of 4%-silicon transformer steel, and the manufacture of aluminium-killed steels and hardened forged steel rolls.—R. A. R.

Construction and Repair of Open-Hearth Furnaces. D. C. Muir. (Journal of The Iron and Steel Institute, 1947, vol. 157, Dec., pp. 481–491).

Fundamentals of Open-Hearth Checkerwork Design. H. W. Potter. (American Institute of Mining and Metallurgical Engineers: Steel, 1947, vol. 121, Dec. 8, pp. 112–120). The design of checker chambers is considered and methods of calculating their length, width, height, and checker volume are explained.—R. A. R.

All-Basic Open Hearth Furnace to Be Used for Experimental Purposes. (Blast Furnace and Steel Plant, 1947, vol. 35, Oct., pp. 1209–1212). **All Basic Open-Hearth**

Furnace Built by Carnegie-Illinois. (Industrial Heating, 1947, vol. 14, Oct., pp. 1721–1732). *See* Journ. I. and S.I., 1948, vol. 158, Jan., p. 150.—R. A. R.

The Rapid Production of Steel. Its Recent Progress. R. Perrin. (Société Française de Métallurgie : Revue de Métallurgie, 1946, vol. 43, July–Aug., pp. 185–191). Progress during the last ten years in the rapid production of steel at the Ugine Works is reviewed.—R. F. F.

Tilting Open-Hearth Furnace Process. A. Jackson. (Iron and Coal Trades Review, 1948, vol. 156, Jan. 2, pp. 19–21). The tilting open-hearth, the fixed open-hearth, and the basic-Bessemer processes are contrasted and compared, with special reference to type of product, metallurgical factors, and costs. After a brief review it is considered that only the tilting-open-hearth and the basic-Bessemer processes can satisfactorily deal with high percentages of phosphoric iron.—J. R.

Use of Oxygen in Open Hearth Practice for Carbon Reduction. F. B. Lounsberry and G. V. Slottman. (Yearbook of the American Iron and Steel Institute, 1947, pp. 234–263). *See* Journ. I. and S.I., 1947, vol. 157, May, p. 132.

Oxygen-Accelerated Combustion in Open Hearth Furnaces. E. T. W. Bailey. (Iron and Steel Engineer, 1947, vol. 24, Nov., pp. 35–41). Theoretical and practical aspects of the use of oxygen, introduced with the fuel, for accelerating combustion in the open-hearth steel furnace are discussed. Some results of trials with oxygen-oil fired furnaces, made by the Steel Company of Canada, Ltd., at Hamilton, Ontario, are reported. Fuel rates up to 700 U.S. gal./hr. were obtained in a 180-ton furnace, using a helicoidal insert in the burner to increase mechanically the mixing of oil and oxygen. Typical flame photographs are reproduced.—C. O.

The Use of Gaseous Oxygen in Metallurgical Processes. G. V. Slottman and P. M. Hulme. (Metal Progress, 1947, vol. 52, Dec., pp. 963–967). Medium-scale (10–100 tons/month) applications of high-purity oxygen in steelmaking processes are discussed. They include decarburization in the open-hearth, treatment of hot metal in the mixer to give a low-sulphur, low-silicon, high-temperature product, and increasing the rate of meltdown of scrap covered with molten metal by accelerating the lime boil. Large-scale trials have shown the practicability of these uses of oxygen.—C. O.

Use of Oxygen in the Open Hearth Furnace. (Blast Furnace and Steel Plant, 1947, vol. 35, Aug., pp. 949–956 ; Sept., pp. 1091–1095 ; Oct., pp. 1224–1226). The processes, equipment, and methods of application for the use of oxygen through the main burners, through jet devices, through auxiliary burners, and through the checkers of open-hearth furnaces are described and illustrated.—J. R.

The Utilization of Manganese in the Basic Open-Hearth Process. H.- J. Krabiell. (Stahl und Eisen, 1947, vol. 66–67, Dec. 4, pp. 420–424). A method for evaluating the factors affecting the utilization of manganese in the open-hearth process is explained. The factor of greatest importance is the amount of manganese in the charge ; with this kept constant, next in importance is the total iron in the slag. With this second factor constant, increasing basicity improves the manganese utilization, as does an increase in temperature. The factors affecting the ratios of concentrations of manganese and phosphorus in the bath and slag were also studied. When the amounts of manganese and phosphorus in the charge are constant, this ratio rises with increasing basicity and increasing total iron in the slag, and falls with increasing temperature.—R. A. R.

Influence of Carbon on the Equilibria between Steel and Slag in the Acid Open-Hearth Furnace. P. Herasymenko. (Journal of The Iron and Steel Institute, 1947, vol. 157, Dec., pp. 515–525).

Items of Controllability in the Open Hearth Combustion Process. A. J. Fisher. (Yearbook of the American Iron and Steel Institute, 1947, pp. 201–233). *See* Journ. I. and S.I., 1947, vol. 157, Nov., p. 466.

Melting Steel and High-Duty Irons in an Oil-Fired Rotary Furnace. W. J. Roscrow. (Foundry Trade Journal, 1947, vol. 83, Dec. 11, pp. 303–305). The production of carbon steels and high-duty irons in a 30-cwt. oil-fired rotary furnace at the Camborne works of Messrs. Holman Bros., Ltd., is discussed, and particulars are given of furnace operation and the preparation of the rammed monolithic acid refractories.—J. R.

Electric Steelmaking in the United States. (Journal du Four Electrique, 1946–47, vol. 55, Dec.-Jan., p. 96). The present position of electric-furnace steelmaking in the United States is briefly surveyed.—R. F. F.

More Time for Bath Alterations Provided by Use of Spectrograph in Steel Plants. B. W. Bowen. (American Institute of Mining and Metallurgical Engineers : Steel, 1947, vol. 121, Dec. 29, pp. 69–72). Examples are cited of the time saved in obtaining determinations of elements in bath samples by the use of the spectrograph.—R. A. R.

Instrumentation. G. R. Bashforth. (Iron and Steel, 1947, vol. 20, Dec., pp. 639–643). The application of instruments to open-hearth-furnace control is discussed with special reference to (*a*) combustion control, (*b*) reversal control, (*c*) roof-temperature control, and (*d*) roof-pressure control. A diagrammatic arrangement for a suggested control system is appended.—J. R.

Constitution and Mineralogy of Steelmaking Slags. J. E. Garside. (Iron and Coal Trades Review, 1947, vol. 155, Dec. 19, pp. 1211–1218 ; Dec. 26, pp. 1247–1252). In the first section of this article a survey is made of the present state of knowledge regarding the constitution and properties of steelmaking slags, with special reference to physical methods of control. In the second section the relationship of slag fluidity to various factors is dealt with, and the application of micro-examination to solidified slags and the measurement of basicity by means of hydrogen-ion determinations are discussed.—J. R.

The Mineralogy of Basic Open Hearth Slags. J. L. Mauthe and K. L. Fetters. (Yearbook of the American Iron and Steel Institute, 1947, pp. 264–298). *See* Journ. I. and S.I., 1947, vol. 157, Nov., p. 468.

Mould-Weight/Ingot-Weight Ratio and Its Relation to Mould Consumption. N. H. Bacon. (Journal of The Iron and Steel Institute, 1948, vol. 158, Jan., pp. 81–95).

Ingot Surface Defects—Formation of "Double Skin" or "Curtaining" on Top-Poured Mild-Steel Ingots. P. Walker. (Journal of The Iron and Steel Institute, 1948, vol. 158, Jan., pp. 96–98).

The Defects of Steel Ingots. De Sars. (Revue de Métallurgie, 1946, vol. 43, May-June, pp. 137–155). Ingot defects and methods of prevention are discussed under three categories, namely, skin defects, cracks, and axial porosity. The need for control of composition of the steel with sulphur and phosphorus not exceeding 0·015% each, is stressed, and, in the case of chromium steels, the amount of chromium oxide must be as low as possible.—R. F. F.

The Metallurgy of Cold Reduced Sheets. C. L. Altenburger. (Yearbook of the American Iron and Steel Institute, 1947, pp. 459–494). *See* Journ. and S.I., 1947, vol. 157, Nov., p. 468.

FOUNDRY PRACTICE

Foundries in Spain—Cupola Melting Results with Indigenous Materials. A. J. G. Smith. (Iron and Steel, 1947, vol. 20, Dec., pp. 643–644). Operating data for six foundries in the Barcelona region are tabulated and reviewed in a consideration of melting results in the Spanish foundry industry for a period when, owing to war-time conditions in the rest of Europe, imported raw materials were not available. It is considered that twice as much coke per unit weight of iron produced was required than would have been the case if best-quality English coke had been used.—J. R.

Belgian Foundries. V. Delport. (Foundry, 1947, vol. 74, Nov., pp. 93, 218–222). The post-war position of the iron and steel foundries in Belgium is reviewed and some particulars are given of the plant and capacity of Fonderies Nestor Martin near Brussels, Fonderie Moons at Zelem, Fonderies Foulon at Liége, and the Cockerill and Esperance-Longdoz foundries near Liége.—R. A. R.

The Modernisation and Mechanisation of the Foundry Industry. G. R. Norguet. (Association Technique de Fonderie : Foundry Trade Journal, 1947, vol. 83, Dec. 18, pp. 325, 332). The general application of mechanization in the foundry is discussed with special reference to certain post-war aspects of the industry in France. The question is considered important for the entire national economy as well as for individual concerns, and some essentials for speedy and economic re-equipment are reviewed.—J. R.

Mechanised Grey Iron Foundry Practice. W. J. Blanch. (Australian Institute of Metals : Australasian Engineer, 1947, Nov. 7, pp. 86–92). Details are given of the layout and foundry practice at a mechanized grey-iron foundry built in 1941 at Adelaide.—C. O.

New Gray Iron Foundry Combines Efficiency and Cleanliness. W. G. Gude. (Foundry, 1947, vol. 74, Nov., pp. 76–81). A description with numerous illustrations is given of the new foundry of the Wells Manufacturing Co., near Chicago where grey iron valve tappets are cast, machined and heat-treated.—R. A. R.

Melting in the Cupola with Oxygen-Enriched Blast. L. I. Levi. (Kislorod, 1947, No. 3, pp. 1–9). [In Russian]. Although the work of Morave (Journ I. and S.I., 1930, No. 1, p. 583 ; Mechanical Engineer, 1930, vol. 52 ; Canadian Foundryman, 1931, vol. 22, No. 2) whose data and conclusions are examined in detail, confirmed the theoretical expectation of increased cupola efficiency and output resulting from oxygen-enriched blast and showed that no deleterious effects on the linings were produced, the cost of oxygen in the period 1930–1940 made such enrichment uneconomical.

A series of experiments on this process have now been conducted at a Moscow plant. The cupola had apparatus for measuring the weights of the charges and casts and the temperature of the latter ; the pressure, temperature and composition of the blast ; and the inwall temperatures at three levels up the stack. Chemical analyses of samples of stack gas were carried out on each cast, and the fluidity of the iron was determined. In the experiments a 1-hr. run on ordinary blast was followed by 10–15 min. off blast, during which the fore-hearth was completely emptied, and then by a 1-hr. run on oxygenated blast. The following conclusions can be drawn : (1) Under otherwise similar conditions, the output of the cupola is a function of the concentration of oxygen in the blast ; the maximum used (31%), more than doubled the normal output. (2) With identical charges and almost identical chemical composition, the fluidity of the metal produced with oxygen-enriched blast was 10–84% greater than that of metal produced with air blast. Oxygen-enrichment of the blast can cause the temperature of the cast to reach about 1500° C. and it gives a much smoother working of the cupola. (3) Oxygen-enrichment of the blast decreases the iron in the slag, increases the silicon and manganese in the metal, and decreases the sulphur picked up by the metal. The carbon in the metal is, in general, unchanged. (4) The CO_2/CO ratio of the stack gas is increased. (5) The ratio heat-in-metal/heat-in-gas is increased from 0·96–1·80 to 1·6–3·2.

A higher stack should, theoretically, give an even greater efficiency. The experiments showed the possibility of at least partially replacing the duplex process for the melting of high-quality cast irons and wrought iron by the use of oxygenated blast in the ordinary cupola. It was also found that the coke in the charge can be reduced by about 4% and still give metal at an elevated temperature. The average oxygen consumption during the trials was 60 cu.m./ton of iron cast.—S. K.

Characteristics of a Steelworks Cupola. (Fonderie, 1946, Mar., pp. 110–113). An account is given of the estimation of the dimensions of a cupola of a given capacity. Various types of tuyeres are illustrated and factors affecting the pressure and flow of the blast are mentioned.—J. C. R.

Cast-Iron Roller Conveyors. J. Timbrell. (Foundry Trade Journal, 1947, vol. 83, Dec. 18, pp. 333–336). Details are given of the production of cast-iron gravity roller conveyors for internal use in the foundry. It is claimed that rollers produced by the method described require no machining whatsoever and that they can be assembled complete, after the normal fettling attention. A supply of the conveyors has withstood several years of hard use without any appreciable signs of wear, compared with some steel rollers operating under the same conditions.—J. R.

Side-Blown Converter Producing Carbon and Alloy Steels. F. Cousans. (Institute of British Foundrymen : American Foundryman, 1947, vol. 12, Nov., pp. 30–34). *See* Journ. I. and S.I., 1947, vol. 157, Nov., p. 468.—R. A. R.

Coatings for Foundries and Steelworks. M. Guédras. (Métallurgie, 1947, vol. 79, June, pp. 13–14). The author gives particulars of mould washes, parting powders, and other refractory mixtures used for coatings in the foundry.—R. A. R.

Bentonite in Foundry Sands. H. Soyer. (Revue des Produits Chimiques, 1947, vol. 49, June 15–30, pp. 97 and 99). The addition of bentonite to reclaimed foundry sands, to improve the bond, is suggested.—R. F. F.

Uses of Bentonite. (Revue des Produits Chimiques, 1946, vol. 48, Mar. 15–31, pp. 37–42). The uses of bentonite are reviewed.—R. F. F.

Methods and Equipment for the Technical Investigation of Moulding and Core Sands. L. Jeníček. (Archiv für Metallkunde, 1947, vol. 1, Jan., pp. 83–94). The equipment and modern methods of determining the following properties of moulding and core sands are described : (*a*) Moisture content ; (*b*) compressibility ; (*c*) permeability ; (*d*) strength ; and (*e*) wear-resistance.—R. A. R.

Visual Analysis of Sand Grain Distribution. C. A. Sanders. (Foundry, 1947, vol. 74, Nov., pp. 83–84, 216). Foundry sand control and an easy method of demonstrating the results of screen analyses are discussed. If the quantities of sand left on each of a series of screens are placed in separate tests tubes in a row in front of a board marked off in per cent., a line joining the tops of the different sand columns can be visualized or drawn, and any departure from the scheduled curve is easily seen.—R. A. R.

Moulding Sand and Moulding-Sand Resources in Germany, Austria, and Czechoslovakia. H. Udluft. (Archiv für Metallkunde, 1947, vol. 1, Jan., pp. 49-53). The refractoriness and permeability of moulding sands is related to their mineralogical structure. Brief particulars of the moulding-sand resources of Germany, Austria, and Czechoslovakia are given.—R. A. R.

The Geological Conditions of the Moulding-Sand Resources of Czechoslovakia. J. Vachtl. (Archiv für Metallkunde, 1947, vol. 1, Jan., pp. 53–56).

The Nature of Clay Binders in Moulding Sands and Their Significance in Foundry Practice. K. Endell. (Archiv für Metallkunde, 1947, vol. 1, Jan., pp. 57–63) Recent literature on the nature of clay in moulding sands and the effect of clay on their strength and permeability is reviewed. Test data are presented which show that the green shear strength of a sand increases as the quantity of exchangeable bases in the clay mineral portion of a natural moulding sand increases. It is also shown that the sintering capacity of a sand at 1400° C. and its suitability for specific purposes can be predicted when the chemically determined fluxes (iron oxide, alkaline earths and alkalis) in the slimes and the total quantity of slimes are known.—R. A. R.

The Colloidal-Chemical Theory for Inorganic Binders in Moulding Sands. H. Reininger. (Archiv für Metallkunde, 1947, vol. 1, Jan., pp. 63–73). The structure of natural core and moulding sands and its significance in determining their use in the foundry are discussed. A distinction is made between the clay binders of high and low hygroscopicity; the sands containing the former type of clay are superior.

A theory for the behaviour of moulding sands is developed which covers sands containing either clay or cement; this theory provides the foundryman with the recipe for preparing synthetic sands with inorganic binders of high hygroscopicity in such a way that the product will have properties equivalent to those of a natural sand which may be situated a long distance from the foundry.—R. A. R.

Core Binders. H. Huttenes. (Archiv für Metallkunde, 1947, vol. 1, Jan., pp. 74–76). The properties and applications of various core binders are discussed with particular reference to dry binders.—R. A. R.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Practical Heat Treatment. H. Pfahl and G. D. Rahrer. (Steel Processing, 1947, vol. 33, Oct., pp. 630–634). Concise explanations are given of the terms normalizing, annealing, quenching, tempering, austempering, and martempering. These processes are illustrated by different forms of S-curves and micrographs.—R. A. R.

An Investigation of Tempered Chromium–Silicon Spring Steel. H. J. Elmendorf. (American Society for Metals, 1948, Preprint No. 1). This paper presents the results of an investigation of the effects of heat-treatment on tempered chromium–silicon spring steel. The tension stress-strain curves for stress-relieved, blued, chromium–silicon spring wires show marked changes in shape as a function of the blueing temperature, and these changes have been found to be associated with the hardness of the tempered wire.—R. A. R.

The Heat-Treatment of Steels without Decarburisation. R. A. P. Misra. (Metallurgia, 1947, vol. 36, Oct., pp. 327–330). A short account is given of experiments on the heat-treatment of steels in a non-decarburizing atmosphere generated by the combustion of paraffin in a type of burner known as the "Paragen."—C. O.

Advantages and Applications of Carbon Restoration. O. E. Cullen. (Steel, 1947, vol. 121, Nov. 17, pp. 94–95, 121–122). A process for restoring carbon to decarburized steel parts by heating in a controlled atmosphere is briefly outlined, and typical applications are indicated. C. O.

Liquid Carburizing of Sintered Steels. G. Stern and J. Greenberg. (Powder Metallurgy Bulletin, 1947, vol. 2, Sept., pp. 85–89). An investigation of the practicability of carburizing sintered powder-steel compacts in liquid salt baths is reported. It was found possible effectively to remove residual salts after oil-quenching, and so prevent abnormal corrosion. Very shallow cases of microhardness equivalent to Rockwell *C* 62–70 were obtained by liquid carburizing at 1450–1550° F.—C. O.

Continuous Gas Carburizing of Steel without a Gas Generator. W. H. Holcroft and E. C. Bayer. (Materials and Methods, 1947, vol. 26, Oct., pp. 92–93). A process is described in which the gas for diluting the hydrocarbon gases in carburizing atmospheres, normally generated in a separate unit, is obtained by recirculation of the partially spent gas from the furnace chamber. —C. O.

Continuous Carburizing and Hardening of Piston Pins at the Ford Rouge Plant. (Industrial Heating, 1947, vol. 14, Oct., pp. 1580–1592, 1755–1760). A description is given of two new continuous gas-fired furnace installations at the River Rouge Plant of the Ford Motor Company the combined capacity of which is 4000 carburized, hardened, and tempered gudgeon pins per hour.—R. A. R.

Carbon Concentration Control. E. G. de Coriolis, O. E. Cullen, and J. Huebler. (Transactions of American Society for Metals, 1946, vol. 38, pp. 659–685). *See* Journ. I. and S.I., 1946, No. II, p. 135A).

Development of Temper Brittleness in Alloy Steels. W. S. Pellini and B. R. Queneau. (Transactions of American Society for Metals, 1947, vol. 39, pp. 139–161). *See* Journ. I. and S.I., 1946, No. II, p. 138A).

Isothermal Heat Treatment Aids Bearing Production. P. A. Cushman. (Iron Age, 1947, vol. 160, Nov. 27, pp. 76–77). A description is given of the salt-bath heat-treatment equipment of McGill Manufacturing Co., Incorporated, which has a capacity of 500 lb. of bearings per hr.—R. A. R.

The Flame-Hardening of Steel. H. Kalpers. (Metalloberfläche, 1947, vol. 1, July, pp. 157–160). The advantages of the flame-hardening process are discussed and the equipment is described.—R. A. R.

Electric Salt Baths for Wire Processing. H. J. Babcock. (Wire and Wire Products, 1947, vol. 22, Oct., pp. 751–760). The advantages of heating in immersed-electrode salt baths over other methods for the annealing, spheroidizing, and patenting of wire are enumerated, and typical modern installations are described.—C. O.

Induction Hardens Tricky Machine-Tool Parts. L. J. Sheehan. (Machinist, 1947, vol. 91, Dec. 6, pp. 1097–1100). Descriptions are given of the induction-heating equipment and the coils of various shapes for hardening different tools.—R. A. R.

The Nitriding of Tools. J. Dàsek. (Hutnické Listy, 1946, vol. 1, No. 5, pp. 101–107). [In Czech]. The nitriding of high-speed-steel tools in salt baths is described with data on the influence of the immersion time on the depth and hardness of the nitrided layer. Experience in machining with nitrided tools is related.—R. A. R.

Effect of Stabilizing and Stress Relief Heat Treatment for 18-8 Stainless. W. G. Hubbell. (Aircraft Engineering, 1947, vol. 19, July, pp. 225–226, 227–228). *See* Journ. I. and S.I., 1947, vol. 157, Dec., p. 648.—R. A. R.

Heat Economy in Annealing and Hardening. E. Neuhäuser. (Stahl und Eisen, 1947, vol. 66–67, Oct. 9, pp. 351–355). The consumption of heat in heat-treatment operations is considered. Two examples from full-scale production, namely, a shear blade and a pressing die, are discussed, and complete analyses are made of the time and heat consumptions in the many processes from casting the ingot to hardening the finished part. Finally, the advantages of using salt-baths in conjunction with hardening furnaces are pointed out.—R. A. R.

Ores from Krusna Hora Used as Annealing Ores for Malleable Iron Castings. Z. Hostinský. (Hutnické Listy, 1946, vol. 1, No. 2, pp. 31–34). [In Czech].

Stress-Relieving in Welds by Heat-Treatment at Relatively Low Temperatures. O. Forsman and K. G. Olsson. (Statens Provningsanstalt, Stockholm, 1947, Report No. 98). [In Swedish]. Stress-relieving treatments for welds in pressure vessels too large for ordinary annealing furnaces were investigated. Boiler-steel plate 30 mm. thick was butt-welded and the changes in dimensions after 12–15 hr. at 200°, 300°, and 550° C. with slow-cooling were measured. The welding stresses were appreciably diminished and equalized by heating to 200° and 300° C. and cooling slowly. It is recommended that such large vessels be annealed by treating with hot air or steam at as high a temperature as possible before being put into service.—R. A. R.

The Interrupted Quench and Its Practical Aspects. H. E. Boyer. (Transactions of American Society for Metals, 1946, vol. 38, pp. 209–238). *See* Journ. I. and S.I., 1947, vol. 155, Feb., p. 307.

The Tempering of High Alloy Tool Steels. G. A. Roberts, A. H. Grobe, and C. F. Moersch, jun. (Transactions of American Society for Metals, 1947, vol. 39, pp. 521–548). *See* Journ. I. and S.I., 1946, No. II, p. 137A).

ROLLING-MILL PRACTICE

The Development in the Demand, and Planning the Production of Rolled Steel. W. Asbeck. (Stahl und Eisen, 1947, vol. 66–67, Nov. 6, pp. 389–395). A comprehensive review of rolling-mill processes is presented which includes process data on the production of billets and many finished sections as well as tubes. Electricity and manpower requirements are given special consideration.—R. A. R.

Roll Deflection. A. B. Cox. (Machine Design, 1947, vol. 19, Nov., pp. 147–150). Formulæ are presented which enable the deflection due to bending and shear at any point along a roll to be calculated.—C. O.

Electrical Equipment for the Sendzimir Cold Strip Mill. H. W. Poole. (Iron and Steel Engineer, 1947, vol. 24, Nov., pp. 43–51). The selection and operation of the electrical equipment for the Sendzimir cold-strip mill, in which small work or back-up rolls are driven by large, high-speed D.C. motors, are illustrated by considering typical data for a 25-in. mill rolling stainless-steel strip from 0·065 in. to 0·005 in. thick at a speed of 250–500 ft./min.—C. O.

Calculating the Forces Arising and the Power Requirements in the Mannesmann Tube-Rolling Process. A. Geleji. (Iron and Steel Institute, 1948, Translation No. 329). This is an English translation of a paper which appeared in Royal Hungarian Palatine Joseph University, Publication of the Department of Mining and Metallurgy, 1941, vol. 13, pp. 208–223 (*see* Journ. I. and S.I., 1947, vol. 155, Feb., p. 308).—R. A. R.

The Theoretical Problems Connected with the Construction of Roll Stands. A. Geleji. (Iron and Steel Institute, 1948, Translation Series, No. 330). This is an English translation of a paper which appeared in Royal Hungarian Palatine Joseph University, Publication of the Department of Mining and Metallurgy, 1941, vol. 13, pp. 224–242. (*See* Journ. I. and S.I., 1947, vol. 155, Feb., p. 308).

The Rolling of Metals: Theory and Experiment. Part XIII. Torque, Deformation Work and Rolling Horsepower. Part XIV. Methods Used in Practice for the Calculation of Rolling Load and Horsepower. Part XV. Discussion of Certain Practical Rolling Problems in the Light of the Theory of Rolling. L. R. Underwood. (Sheet Metal Industries, 1946, vol. 23, Dec., pp. pp. 2319–2328; 1947, vol. 24, Jan., pp. 73–84, 90; Feb., pp. 299–306, 310; Mar., pp. 531–538, 540; Apr., pp. 753–757; May, pp. 953–962; June, pp. 1155–1162; July, pp. 1352–1360, 1366; Aug. pp. 1563–1568, 1580; Sept., pp. 1769–1744, 1782; Oct., pp. 1984–1989; Nov., pp. 2199–2205; Dec., pp. 2405–2409). Continuation of a series of articles (*see* Journ. I. and S.I., 1947, vol. 155, Feb., p. 307).—R. A. R.

Report of A.I.S.E. D.C. Mill Motor Standardization Committee. F. O. Schnure. (Iron and Steel Engineer, 1947, vol. 24, Dec., pp. 79–82). An outline is given of the history and work of the D.C. Mill Motor Standardization Committee of the Association of Iron and Steel Engineers.—J. R.

A.I.S.E. Standard No. 1—D.C. Mill Motor Standards. (Iron and Steel Engineer, 1947, vol. 24, Dec., pp. 76–78. The dimensions and ratings laid down for D.C. mill motors in Standard No. 1 of the Association of Iron and Steel Engineers are described and tabulated.—J. R.

Use of Wood and Synthetic Resin Bearings in Rolling Mills. M. Quillatre. (Revue de Métallurgie, 1941, vol. 38, Oct. pp. 253–271; Nov., pp. 285–298). Wood and synthetic resins are compared with bearing metals for the manufacture of rolling-mill bearings. Woods and resins used, shapes, lubricants, and results obtained with these substitute materials are discussed. Examples showing the type of mill, the bearings and lubricant, and costs of bearings are tabulated.—R. F. F.

Study on Rolling Mill Bearings. A. Beneteau. (Revue de Métallurgie, 1941, vol. 38, Aug., pp. 193–206). Wood (quebracho and gaïacum), compressed cotton cloth impregnated with resin, and impregnated wood, are discussed from the point of view of their utility as materials for rolling-mill bearings. The materials are lubricated with cold water. The use of impregnated cotton cloth for the bearings in a Morgan wire mill and a Morgan slab and billet mill is described.—R. F. F.

Design of a Mill for Rolling Semi-finished Products. J. J. Curtin. (Yearbook of the American Iron and Steel Institute, 1947, pp. 495–508). *See* Journ. I. and S.I., 1947, vol. 157, Nov., p. 471.

Improved Design for Rail and Structural Mills. H. F. Voigt and F. Eisel. (Iron and Steel Engineer, 1947, vol. 24, Dec., pp. 55–69). A detailed description is given of a combined blooming, rail, and structural mill of American design, built for a European steelworks. The equipment includes a 46 × 100-in. two-high reversing blooming mill, a 35 × 92-in. two-high reversing break-down mill, and 35- and 32-in. rail and structural mills. The installation is intended for the output of about 1,000,000 tons of finished and semi-finished products from ingots measuring up to 25 × 58 in., and weighing up to 22,000 lb.—J. R.

New Precision Light-Section Mill. T. Bishop. (Iron and Coal Trades Review, 1948, vol. 156, Jan. 2, pp. 12–15). A description is given of the new precision mill installed at the Darlington works of the Darlington and Simpson Rolling Mills, Ltd., for the production of special light sections. The estimated output of 75 tons

per shift has been exceeded on many occasions since the mill has gone into production. (*See* Journ. I. and S.I., 1948, vol. 158, Jan., p. 153).—J. R.

The Joliet Coarse Rod Mill. R. R. Snow. (Yearbook of the American Iron and Steel Institute, 1947, pp. 509–518). *See* Journ. I and S.I., 1947, vol. 157, Nov., p. 471.

Rod Mills and Rod Reels. T. J. Llewelyn. (United Effort, 1947, vol. 27, Sept., pp. 4–7). The development of rod mills, and their accessory equipment, is briefly sketched.—M. A. V.

New Canadian Continuous Strip Mill. F. J. Erroll. (British Steelmaker, 1947, vol. 13, Dec., pp. 612–613). The second part of a three-stage expansion programme planned by the Steel Company of Canada has been completed by the erection of a 56-in. six-stand four-high continuous hot-strip mill at the Company's Hamilton (Ontario) works.—J. R.

Progress in Steel Pipe Manufacture with Particular Reference to Seamless Pipe. E. N. Sanders. (Yearbook of the American Iron and Steel Institute, 1947, pp. 446–458). *See* Journ. I. and S.I., 1947, vol. 157, Nov., p. 472.

New Silicon Strip Cold Mill. F. R. Grant. (Iron Age, 1947, vol. 160, Nov. 20, pp. 79–83). A description is given of the new tandem cold mill for high-silicon steel sheet and strip of the Allegheny Ludlum Steel Corporation.—R. A. R.

Bending Machinery. E. L. Tinley. (British Engineering Export Journal, 1947, vol. 30, Nov., pp. 667–674). Illustrated particulars are given of some types of British bending machines available for bars, sections, plates, and sheets.—R. E.

MACHINERY FOR IRON AND STEEL PLANT

Modern Pulverised-Fuel Steam-Raising Plant. T. Smeaton. (Iron and Coal Trades Review, 1947, vol. 155, Dec. 19, pp. 1206–1210). An outline is given of the development and present design of coal pulverizers and large pulverized-fuel-fired boilers used at central electric-power stations. Although the equipment dealt with far exceeds the capacities hitherto employed in steelworks in this country, it is applicable in a modified form; an example of such modification is the boiler plant at present being installed by the Consett Iron Co., Ltd., for the use of blast-furnace gas, coke-oven gas, or pulverized fuel, as desired.—J. R.

Power Cycles and Power Generating Equipment. A. R. Smith. (Iron and Steel Engineer, 1947, vol. 24, Nov., pp. 65–72). Recent trends and developments in power-generating equipment, in particular in steam turbines, are discussed briefly.—C. O.

The Maintenance of High-Pressure Hydraulic Installations. (Stahl und Eisen, 1947, vol. 66–67, Dec. 4, pp. 428–430). Recommendations are made on the maintenance of hydraulic pressing machinery, pipelines, and fittings.—R. A. R.

" Harnessed " Air in the Metalworking Industry. (Compressed Air and Gas Institute: Steel, 1947, vol. 121, Nov. 3, pp. 94–102, 121–122). The types of air compressors and pneumatic tools used in metallurgical industries are discussed.—C. O.

A Crane for Travelling Round Corners and Sharp Curves. O. Roth. (Schweizerische Bauzeitung: Stahl und Eisen, 1947, vol. 66–67, Nov. 6, pp. 399–400). A brief description is given of an overhead travelling crane and track designed so that the crane can move round curves of very small radius. A short turntable is constructed on the inner rail at the corner whilst the outer rail is continuous; automatic safety switches are included.—R. A. R.

Selection of Gear Ratios for Crane Bridge Drives. J. L. Skeehan. (Iron and Steel Engineer, 1947, vol. 24, Dec., pp. 83–88). Calculations and formulæ for the determination of crane-bridge drives are outlined and discussed.—J. R.

Overhead Lifting Equipment. G. V. Sadler. (British Engineering Export Journal, 1947, vol. 30, Dec., pp. 802–810). Illustrated particulars are given of various types of overhead lifting equipment for use in engineering workshops and foundries.—R. E.

Measures for Protection against Frost Damage, Based on the Experience of Last Winter. H. Steinmetz. (Stahl und Eisen, 1947, vol. 66–67, Oct. 9, pp. 355–361). Means of protecting idle plant from damage by frost are discussed.—R. A. R.

LUBRICANTS AND LUBRICATION

Rapid Methods of Grease Analysis. (A.S.T.M. Bulletin, 1947, Oct., pp. 73–78). This is a report by Section I on " Chemical and General Laboratory Tests for Lubricating Grease " of Technical Committee G on Lubricating Grease, of Committee D-2 on Petroleum Products and Lubricants, appointed by the A.S.T.M. to study methods of grease analysis. Brief summaries and comments on the methods of analysis are given and these are followed by an appendix in which the complete procedures are described. Abstracts of the papers in this appendix follow.—R. A. R.

Rapid Methods for the Determination of Oil in Lubricating Greases. C. J. Boner and G. A. Williams. (A.S.T.M. Bulletin, 1947, Oct., pp. 75–76).

Swan-Finch Control Method (Control Procedure 7-1000). W. C. Bryant. (A.S.T.M. Bulletin, 1947, Oct., p. 77). A method of determining the soap content of lubricating greases, fillers, and the viscosity of mineral oil is described.—R. A. R.

General Electric Co. Soap Determination in Grease. H. A. McConville. (A.S.T.M. Bulletin, 1947, Oct., pp. 77–78).

Analysis of Grease (Sinclair Method)—Routine Method, as Applied to Rod Cup Journal and Rod Cup Greases. N. J. Gothard. (A.S.T.M. Bulletin, 1947, Oct., p. 78).

Determination of Sodium Soap in Greases Known to Contain Only Sodium Soap and No Interfering Fillers. W. S. Palmer. (A.S.T.M. Bulletin, 1947, Oct., p. 78).

A Gear and Lubricant Tester—Measures Tooth Strength or Surface Defects. E. A. Ryder. (A.S.T.M. Bulletin, 1947, Oct., pp. 69–73). A description is given of a simple machine for bench-testing gear materials and gear lubricants. The load on the gears under test can be changed without stopping the machine.—R. A. R.

Silicone Greases. A. E. Williams. (Engineering and Boiler House Review, 1947, vol. 62, Nov., pp. 328–329, 331). Details are given of the physical properties and characteristics of three silicone ball-bearing lubricants. These lubricants are very stable under wide extremes of temperature conditions—as low as −95° F., and as high as 480° F.—C. O.

WELDING AND FLAME-CUTTING

Metal Arc Transfer As Influenced by Some Materials in the Covering of Welding Electrodes. C. T. Grayley. (Welding Journal, 1947, vol. 26, Nov., pp. 693-s–704-s). Tests are described which demonstrated the effect of the basicity of welding electrode coating materials on

the material transferred through the arc. As the basicity of lime-type electrode coating is increased, the carbon, manganese, chromium, and vanadium contents of the deposited weld metal also increased. The recovery of nickel and uranium in weld deposits was not affected by changes in the basicity of electrode coatings of this type. Decreasing the particle size of the ferro-alloys in the coatings considerably increased the recovery of manganese and molybdenum in the deposited metal.—R. A. R.

Selection of Austenitic Electrodes for Welding Dissimilar Metals. A. L. Schaeffler. (Welding Journal, 1947, vol. 26, Oct., pp. 601-s–620-s). The use of the Maurer microstructure diagram to establish the relationships between chromium–nickel austenitic electrodes and the base metal, when welding dissimilar metals, is explained. A modified form of the Newell-Fleischmann equation is used to convert minor elements into nickel or chromium equivalents so that any alloy can be located on the chromium–nickel diagram. A method for predicting resultant weld composition and microstructure when welding dissimilar metals, which utilizes so-called "dilution direction" lines on the Maurer diagram, is proposed, and examples are given of its use.—C. O.

Composite Alloy Fabrication with the Hidden Arc. H. E. Cable. (Welding Journal, 1947, vol. 26, Oct., pp. 903–906). Applications of the "Hidden Arc" welding process for the deposition and joining of alloys of good wear, abrasion, or corrosion resistance, but poor weldability, are outlined.—C. O.

Metallurgical Conditions of Arc Welding. N. Christensen. (Tidsskrift for Kjemi, Bergvesen og Metallurgi, 1947, vol. 7, No. 7, pp. 102–106). [In Norwegian]. A description is given of an investigation carried out at the welding-rod laboratory of Unitor A/S. The arc-welding process leads to an equilibrium between the deposited metal and slag if heavily coated electrodes are used. The carbon content of the weld metal was far above the equilibrium value. This deviation of the carbon content from its equilibrium value may be explained by the assumption that there is a high external pressure during the slag solidification period.—J. K. A.

Some Metallurgical Aspects of Carbon Steel Spot Welding. J. Heuschkel. (Welding Journal, 1947, vol. 26, Oct., pp. 560-s–582-s). The results of investigations of the influence of carbon content, plate thickness, and initial properties on the shear and direct-tensile strengths of heat-treated and untreated spot welds in steels of up to ½ in. in thickness and containing up to 1·09% of carbon, are presented.—C. O.

The Fundamentals of Spot Welding Steel Plate. W. F. Hess, W. D. Doty, and W. J. Childs. (Welding Journal, 1947, vol. 26, Oct., pp. 583-s–593-s). An experimental study of the variables involved in the spot welding of steel plates, made in order to establish a general procedure for the selection of the optimum welding conditions for various thicknesses and types of steel, is described. It is concluded that: (1) Continuous welding is to be preferred to pulsation welding; (2) the most important welding factors are power level and time; (3) intimacy of contact between the surfaces being welded is essential for consistency; (4) the best welds were obtained with a dome-shaped electrode contact surface of limited diameter; (5) the minimum spacing to limit the reduction in weld diameter, caused by short circuiting, to less than 10% is five times the weld diameter; and (6) the use of electrode temperature for control purposes is not to be recommended.—C. O.

Studies on the Effects of Red Lead Paints on the Quality of Metal-Arc Welds in Structural Steel. R. W. Bennett, R. D. Williams, and C. B. Voldrich. (Welding Journal, 1947, vol. 26, Nov., pp. 653-s–663-s). An investigation was undertaken to determine the effect of red-lead and zinc-chromate base priming paints on the quality of arc welds in structural steels. When the thickness of the dry paint film was less than 3 mils, the paint had no significant influence on the tensile strength of the weld metal or of butt-and fillet-welded joints. The strength, ductility and soundness of the welds depended more on the ability of the welder to overcome the interference of the paint film than on the direct effect of the paint on the weld metal.—R. A. R.

The Manufacture of Cutting Tools with Inset Tips. J. Doumenach. (Mécanique, 1946, vol. 30, Dec., pp. 291–292). The manufacture of the shank and methods of welding on tip are described.—R. F. F.

Welded Frames. H. Gerbeaux. (Machines et Métaux, 1947, vol. 31, Jan., pp. 3–7). The advantages of welded mild steel frames over cast frames, and their design, are described.—R. F. F.

Welding in the Construction of Railway Coaches. M. Reglé. (Revue de la Soudure: Laschtijdschrift, 1947, vol. 3, No. 3, pp. 130–137). The use of welding in the construction of French railway coaches is described.

The Sequence of Welding Passes in Welded Seams. W. Bonhomme. (Revue de la Soudure: Laschtijdschrift, 1947, vol. 3, No. 3, pp. 119–129). General rules for welding technique are given.—R. A. R.

Oxy-Acetylene Pressure Welding. R. Meslier. (Machines et Métaux, 1947, vol. 31, Mar., pp. 79–82). Oxy-acetylene pressure welding, the properties of the welds and their application, are reviewed.—R. C. C.

Some Aspects of Topics Connected with Oxy-Acetylene Welding. A. Leroy. (Société d'Encouragement pour l'Industrie Nationale, Nov. 7, 1942: Métaux, Corrosion, Usure, 1942, vol. 17, Dec., pp. 231–236). Brief notes are given on the following subjects: The oxy-acetylene flame and its thermal and chemical characteristics, pressure welding, cementation, and surface hardening.—J. C. R.

Steel Sheathing of Electric Cables by the Hackethal Process. (British Intelligence Objectives Sub-Committee, 1947, B.I.O.S., Final Report No. 1570: H.M. Stationery Office).

Covered Electrodes and Their Application. W. Hummitzsch. (Werkstatt und Betrieb, 1947, vol. 80, Oct., pp. 260–261). The use of covered electrodes for welding under present conditions in Germany calls for the greatest economy. Methods of applying them to the best advantage are discussed.—R. A. R.

Seam Welding Composite Plates. O. R. Carpenter. (American Society of Mechanical Engineers: Steel, 1947, vol. 121, Dec. 22, pp. 64–65, 83–84). A method for attaching ferrous and non-ferrous alloy sheets to steel sheets by a series of overlapping spot welds is described. The metallurgical considerations involved are discussed.—C. O.

Applications of Argon and Helium in Welding Metals. D. L. Glizmanenko. (Kislorod, 1947, No. 3, pp. 44–51). [In Russian]. A review is presented of recent developments in the application of argon and helium to the welding of metals in Great Britain and the United States.—S. K.

Atomic Hydrogen Welding with Control of Carbon. (Welding, 1947, vol. 15, Oct., pp. 460–464). The applications of the "Athyweld" atomic-hydrogen welding process which is claimed to enable a weld metal of controlled carbon content to be deposited, are described. They include the manufacture of new machine tools, the rebuilding of worn tools, hard-surfacing, and the repair of broken tools.—C. O.

Practical Importance of Hydrogen in Metal-Arc Welding of Steel. S. A. Herres. (Transactions of American Society of Metals, 1947, vol. 39, pp. 162–192). *See* Journ. I. and S.I., 1946, No. II, p. 135A).

Welding Heat-Resisting Alloys for Jet Engine Construction. E. W. Harding. (Welding, 1947, vol. 15, Nov., pp. 504–511, 519). Theoretical and technical considerations in the resistance-welding of special alloy steels are discussed. A method for calculating the correct pressure for seam-welding is explained and a short account is given of a stitch-welding process for joining mild steel to stainless steel.—C. O.

Choose the Right Electrode. W. D. Waller. (Welding, 1947, vol. 15, Aug., pp. 356–365; Oct., pp. 472–479; Nov. pp. 521–529). After a brief discussion of British and American welding-electrode classifications, the characteristics and applications of mild and low-alloy steel electrodes with flux coatings of the rutile, cellulose, iron silicate, and lime types are summarized.—C. O.

Resistance Welding in Mass Production. A. J. Hipperson and T. Watson. (Welding, 1947, vol. 15, July, pp. 307–313; Aug., pp. 366–374; Oct., pp. 480–491; Nov., pp. 530–534; Dec., pp. 580–587). Continuation of a series of articles (*see* Journ. I. and S.I., 1947, vol. 156, July, p. 439). Modern projection welding machines, and the design and maintenance of electrodes are described.—R. A. R.

Resistance Welding. R. T. Gillette. (Materials and Methods, 1947, vol. 26, Nov., pp. 97–108). Recent developments in control, technique, and equipment make the use of resistance welding possible as a fabrication method in almost any engineering plant and on all of the commonly used engineering metals. The advantages and limitations of the method in general are outlined, and the various types of resistance welding and their most economical applications are discussed. Detailed indications regarding the choice of standard or special apparatus are given as an aid to the best selection of equipment.—J. R.

Problems in Resistance Welding Stainless Steel Railway Car Structures. J. H. Van den Beemt. (Welding Journal, 1947, vol. 26, Oct., pp. 837–843). The manufacture of stainless-steel railway carriages is described and illustrated. Details are given of the resistance welding techniques used in the prefabrication and assembly of the six main components.—C. O.

$H = kRI^2t$—A Useful Approach to Resistance Welding. B. G. Higgins. (Sheet Metal Industries, 1947, vol. 24, Aug., pp. 1639–1642; Sept., pp. 1843–1852). The control of the quality of spot-, seam-, and projection-welding by control of each of the variables in the equation for heat input, $H = kRI^2t$, is explained.—C. O.

Shunt Circuit Impedance in Spot Welding $\frac{1}{8}$-, $\frac{1}{4}$-, and $\frac{1}{2}$-In. Mild Steel. R. H. Blair. (Welding Journal, 1947, vol. 26, Oct., pp. 843–848). An investigation of the effects of welding-machine impedance, spot spacing, sheet width, location of shunt path with respect to the throat field, and sheet temperature, on the shunting of current through adjacent welds during the spot welding of mild-steel plates is reported.—C. O.

Continuous Furnace Brazing. C. L. West. (Machinist, 1947, vol. 91, Nov. 15, pp. 1020–1021; Dec. 13, pp. 1132–1134). Vacuum clamping and other methods of assembling parts, and large furnaces for brazing are described and illustrated.—R. A. R.

Electric Furnace Brazing for Mass Production. H. Eickelberg. (Iron Age, 1947, vol. 160, Dec. 18, pp. 56–59). Descriptions are given of continuous electric furnaces which are used for the copper brazing, silver soldering, and bright annealing of metal parts.—R. A. R.

Fundamentals of Oxyacetylene Welding and Cutting. J. I. Banash. (International Acetylene Association: Steel, 1947, vol. 121, Nov. 10, pp. 110–112, 144–149). An elementary account is given of the principles of and equipment for oxy-acetylene welding and cutting, and of the use of the oxy-acetylene flame for hardening, pressure welding, and scarfing.—C. O.

Welding and Flame Cutting Applied to Stainless and Clad Steels. S. F. Danes. (Materials and Methods, 1947, vol. 26, Oct., pp. 102–106). The fabrication of an all-welded paper-pulping machine is described and illustrated. The machine is constructed of nickel-clad steel and chromium-nickel stainless steel. The individual components were cut out by the flux-injection flame-cutting process and welded together with the oxy-acetylene torch.—C. O.

A Brief Review of Brazing Processes. H. R. Brooker. (Sheet and Strip Metal Users' Technical Association: Sheet Metal Industries, 1947, vol. 24, Oct., pp. 2041–2045; Nov., pp. 2253–2257). A general survey is made of the principal aspects of brazing—fluxes, brazing metals, joint design, surface preparation, and heating.—C. O.

Oxygen Cutting. E. Seymour Semper. (Welding, 1947, vol. 15, Jan., pp. 29–33; Feb., pp. 73–78; Apr., pp. 156–163; May, pp. 224–226; June, pp. 280–285; July, pp. 326–329; Aug. pp. 380–385; Oct., pp. 468–472; Nov., pp. 535–536; Dec., pp. 573–579). Continuation of a series of articles (*see* Journ. I. and S.I., 1947, vol. 155, Mar., p. 465).—R. A. R.

Oxy-Gas Cutting—Various Gases Compared with Acetylene. A. H. Taylor and T. Bound. (Welding, 1947, vol. 15, Nov., pp. 536–543). Details are given of oxygen-cutting tests made using acetylene, propane, propane–ether, coal gas, and coal-gas/ether as fuels. It was found that acetylene can be satisfactorily replaced by propane or coal gas, with or without enrichment by ether. The heating and cutting rates were slightly faster, and the oxygen consumption was slightly less, with acetylene than with other gases.—C. O.

CLEANING AND PICKLING

Surface Preparation of Semi-Finished Steel. S. F. Magis. (Iron and Steel Engineer, 1947, vol. 24, Nov., pp. 78–92). The mechanical methods, *i.e.*, chipping and grinding, of removing surface defects from tool-steel ingots and billets are discussed in some detail. The source, and metallurgical methods of preventing the formation of such defects are also considered.—C. O.

Surface Preparation of Semi-Finished Steel. J. W. Deimler. (Iron and Steel Engineer, 1947, vol. 24, Dec., pp. 48–50). Surface preparation of steel billets by mechanical-chipping methods is described and illustrated. It is emphasized that mechanical chippers are essentially production machines and that economically the best results from their use are obtained on billets larger than 4 in. × 4 in. × 5 ft.—J. R.

The Problem of the Economic Use of Acids and the Pickling of Ferrous Metals. J. Bigeon. (Métaux, Corrosion, Usure, 1942, vol. 17, Oct., pp. 182–192). In order to economize in the use of acids, scale is first loosened by mechanical means. Factors affecting the composition of the bath, the use and action of inhibitors, and the recuperation of the pickling bath are discussed.—J. C. R.

Pickling Baskets of Indigenous Materials. (Stahl und Eisen, 1947, vol. 66–67, Dec. 4, pp. 427–428). Descriptions are given of pickling baskets made of wood and other materials with a view to economizing in the use of bronze in Germany.—B. A. R.

The Treatment of Plating and Pickling Wastes. E. W. Mulcahy. (Journal of the Electrodepositors' Technical Society, 1947, vol. 22, pp. 227–242). The treatment of effluent liquors from plating and pickling plants is discussed in some detail. Among the topics mentioned are the neutralization of acids, the precipitation of heavy metals, the removal of cyanide, the construction of treatment tanks, flow and *p*H measurement, the removal of nitrous oxide fumes, rubber linings, the recovery of waste pickle liquors, and plant for the crystallization of ferrous sulphate.—C. O.

Developments in Shot Blasting. R. Ankers. (Manchester Association of Engineers, Jan., 1948, Preprint). A short account is given of the history and development of the sand- and shot-blasting processes for the cleaning of ferrous and non-ferrous coatings. The characteristics of the compressed-air and mechanical-impelling methods are outlined, and the selection of abrasives is discussed in some detail, with particular reference to the danger of silicosis. In conclusion the techniques of shot-peening and vapour blast liquid honing are briefly described.—C. O.

Modern Mechanical Surface Finishing. M. Manler. (Metal Finishing, 1947, vol. 45, Nov., pp. 62–66). The elementary principles and essential practices of mechanical surface finishing, *i.e.*, buffing, polishing, burring, grinding, etc., are reviewed. Various types of polishing wheels are described, together with their respective uses. Other aspects covered are the physical properties of abrasives, selection of correct grain-size, and selection, preparation, and application of glue. The use of cements as an alternative to glue is mentioned.—G. C. J.

Polishing Metals and Polishing Agents. J. H. Frydlender. (Revue des Produits Chimiques, 1946, vol. 48, Feb. 15–28, pp. 22–26; Mar. 15–31, pp. 42–43, 45). Mechanical polishing of metals is reviewed and polishing agents are surveyed.—R. F. F.

The Oxy-Acetylene Flame Cleaning of Steel. G. F. Lee. (Engineering and Boiler House Review, 1947, vol. 62, Dec., pp. 358–360). The preparation by flame-cleaning is described. A series of closely spaced oxy-acetylene jets is passed over the steel, the intense heat drying the surface and causing any mill scale to crack and become detached.—C. O.

PROTECTIVE COATINGS

Machine Designed for High-Speed Metal Plating. A. D. Canner, C. Twele, and T. J. O'Connor. (Materials and Methods, 1947, vol. 26, Nov., pp. 79–82). A description is given of a machine designed for the high-speed deposition of metallic coatings on metal parts. The machine consists of a cabinet with all the necessary controls conveniently mounted and a bracket for receiving the various plating fixtures required. The solution is pumped continuously through a motorized control valve, provision being made for the replenishing of exhausted elements. It is claimed that the apparatus offers a basic unit in which solution velocities reach 100 ft./sec., and in which high current densities are available.—J. R.

Common Plating Bath Troubles—Their Causes and Cure. J. B. Mohler. (Iron Age, 1947, vol. 160, Dec. 11, pp. 98–101, 170). The detection, prevention, and correction of troubles arising in plating baths are discussed at length. A continuous purification system is outlined.—C. O.

Sources of Impurities in Electroplating Solutions. M. B. Diggin. (Monthly Review of the American Electroplaters' Society, 1947, vol. 34, Nov., pp. 1236–1242). Actual experiences are quoted in a review of the sources of the impurities which may be found in electroplating solutions, originating from inorganic and organic impurities in solution, and solid, dispersed, and gaseous impurities.—R. L. B.

Plated Metals and Their Methods of Production. M. Ballay. (Société d'Encouragement pour l'Industrie Nationale, Oct. 24, 1942: Métaux, Corrosion, Usure, 1942, vol. 17, Dec., pp. 221–230). A general account is given of the various methods of plating steel and other metals.—J. C. R.

The Influence of the Basis Metal in Electroplating. R. Piontelli. (International Conference on Electrodeposition: Sheet Metal Industries, 1947, vol. 24, Dec., pp. 2399–2404, 2416). Experiments on the deposition of lead, tin, antimony, and cadmium from simple salt solutions on to various cathodes, at various current densities, are briefly described. At a given current density, the number of centres of crystallization was found to vary considerably with the nature and surface condition of the base metal. Possible mechanisms of electrodeposition are discussed from the point of view of lattice structures.—C. O.

Present Tendencies in the Technique of Electrolytic Deposition. A. Glazunov. (Société Française de Métallurgie: Revue de Métallurgie, 1946, vol. 43, July–Aug., pp. 214–218). The theories on the electrolytic deposition of metals are reviewed.—R. F. F.

Finishing Steel for Decorative and Protective Purposes. R. L. Kenyon. (Yearbook of the American Iron and Steel Institute, 1947, pp. 597–627). *See* Journ. I. and S.I., 1947, vol. 157, Nov., p. 473.

Corrosion Prevention by Sprayed Coatings. H. W. Greenwood. (Mechanical World, 1947, vol. 122, Dec. 5, pp. 596–598). A short account is given of the flame-spraying process for the protection of metals against corrosion.—C. O.

Proceedings of the American Electroplaters' Society, 33rd Annual Technical Sessions. (American Electroplaters' Society, June, 1946). The 33rd Annual Technical Sessions of the American Electroplaters' Society were held in Pittsburgh in June, 1946. Abstracts of the papers of ferrous interest which were presented follow.—C. O.

Wartime Plating Developments in England. A. W. Hothersall. (*Ibid.*, pp. 1–16). A detailed review is given of advances made in England in the technique and testing of electroplating.—C. O.

Summary of Wartime Research on Plating at the National Bureau of Standards. W. Blum. (*Ibid.*, pp. 16–21). A résumé is made of the wartime work of the Electroplating Section of the National Bureau of Standards.—C. O.

Nickel Plating on Steel by Chemical Reduction. A. Brenner and G. E. Riddell. (*Ibid.*, pp. 23–29). A process for the deposition of nickel on steel by the reduction of a nickel salt with hypophosphites in hot ammoniacal solution is described. The steel acts as a catalyst for the reduction, which results in a nickel coating of 96–97% purity.—C. O.

X-ray Diffraction Studies of Electrodeposits. T. Voyda. (*Ibid.*, pp. 33–48). Details are given of X-ray diffraction studies of (*a*) the diffusion of indium into lead, (*b*) the structures of "flash" electrolytic deposits of copper, silver, and nickel on steel, and (*c*) the structure of copper–tin and lead–tin alloy electrodeposits.—C. O.

Electropolishing—What Is Its Status Today? C. L. Faust. (*Ibid.*, pp. 49–73). The limitations and advantages of electropolishing as a commercial process for the removal of metal (obviating the cold working inherent in machining) and surface finishing are discussed at some length, with illustrations of the

results obtained. Details are given of electropolishing techniques for stainless, carbon, and alloy steels, and various non-ferrous metals, and very approximate estimates are made of the costs.—C. O.

Disposing of Plating Room Waste Liquors in Compliance with Stream Pollution Laws. C. J. Lewis. (*Ibid.*, pp. 81–90). Stream-pollution legislation in the United States is discussed, and its effects on the disposal of waste liquors from electroplating are considered.—C. O.

Some Observations on Alkaline Electrotinning. T. G. Timby. (*Ibid.*, pp. 90–102). A brief account is given of the alkaline electrotinning process. Curves obtained during investigations of the current-density distribution for various shapes of anode are reproduced. —C. O.

Electro Tin Plating of Wide Steel Strip at High Speed. S. S. Johnston and G. C. Jension. (*Ibid.*, pp. 102–115). After a short historical account of the development of tinplate, detailed descriptions are given of the pilot and commercial installations of high-speed wide-strip electrotinning equipment by the Weirton Steel Company, Weirton, West Virginia.—C. O.

Examination of Electrocleaned Steel by Electron Diffraction Technique. C. W. Smith and I. L. Karle. (*Ibid.*, pp. 117–127). The determination by electron diffraction, of the chemical composition of steel surfaces cleaned electrolytically in various alkaline solutions under controlled conditions of time, temperature, and current density, is described. It is concluded that so-called "clean" surfaces produced electrolytically on steel never exist as free metal, since the iron combines readily to form oxides or attracts other elements or compounds. The different alkaline solutions produced different electrode films on steel under specified conditions.—C. O.

The Effect of Surface Preparation on the Durability of Organic Coatings. V. M. Darsey. (*Ibid.*, pp. 130–140). Mechanical and chemical methods of preparing metal surfaces before the application of organic coatings are summarized. The removal of all foreign matter, grease, and oil is essential, and for ferrous surfaces the adhesion and durability of the coatings are increased by phosphatizing. Methods of preparing copper, brass, lead, zinc and its alloys, and aluminium for painting are indicated.—C. O.

Coating, Strippable, Spray Type. E. H. Bucy. (*Ibid.*, pp. 141–144). An account is given of the characteristics and applications of the strippable sprayed plastic protective coating known as "Brevon."—C. O.

Natural and Synthetic Rubber in the Electroplating Industry. H. C. Klein. (*Ibid.*, pp. 144–151). A short account is given of the history and present status of the use of rubber linings for equipment handling corrosive liquors.—C. O.

Characteristics of Certain Plastic Films and Coatings. J. W. Shackleton. (*Ibid.*, pp. 162–172). A detailed summary is given of the properties of polythene which make it suitable as a coating for protecting metal surfaces against corrosion. Short accounts are also given of the characteristics of "Lucite" acrylic resin, nylon, and "Teflon" polytetrafluoroethylene polymer as protective coatings.—C. O.

Stripping of Copper from Various Base Metals. F. C. Mathers. (*Ibid.*, pp. 177–181). A critical survey is made of chemical and electrolytic methods of stripping copper from base metals. The chemical reagents considered are conc. nitric acid, chromic acid, and sulphide–cyanide. The electrolytic method considered is that using cyanide solutions.—C. O.

Effect of Impurities and Purification of Electroplating Solutions. D. T. Ewing. (*Ibid.*, pp. 209–211). A short note is made of the work of a Committee of the American Electroplaters' Society studying the effect of impurities and the purification of plating solutions. The work has been confined mainly to the compilation of a bibliography and an investigation of nickel solutions.—C. O.

Polarization at Electrodes in Electroplating Processes. A. L. Ferguson. (*Ibid.*, pp. 215–218). The theory of polarization, or overvoltage, in electrolytes is briefly explained. Mention is made of a bibliography on polarization now being compiled by the American Electroplaters' Society.—C. O.

Parkerising: Growth or Shrinkage? N. A. Tope. (*Ibid.*, pp. 293–304). A detailed account is given of an investigation of changes in the dimensions of high-tensile-steel threaded studs during phosphate coating by the Parker "A" process. Variations from the specified dimension of $-0{\cdot}001$ in. and $+0{\cdot}004$ in. were found during production runs. The large increases are attributed to coarsely crystalline coatings; fine coatings are indicative of small increases or decreases in dimensions. The influence of bath conditions on the changes is discussed.—C. O.

Thickness Testing. A. Ogarev. (Zhurnal Prikladnoy Khimii, 1946, vol. 19, No. 3, pp. 311–315: Electroplating, vol. 1, Dec., pp. 54–60). A method for determining the thickness of electrodeposited metallic coatings is described which utilizes as an end point the change in resistance of an electric circuit through a jet of electolyte impinging on the coated surface at the moment when the base metal is exposed. An electrolyte consisting of 5% of sulphuric acid, 1·5% of ammonium chloride, and 40 c.c./litre of glycerol has been found experimentally to be suitable for testing chromium, nickel, copper, tin, zinc, and cadmium coatings.—C. O.

Rapid Plating Range Test. J. B. Mohler. (Iron Age, 1947, vol. 160, Dec. 4, pp. 75–76). A rapid test for determining the plating range of chromic acid baths is outlined. A test strip is plated in a cell with a slotted screen between the anode and cathode, and compared with a set of standard strips prepared in the same cell.—C. O.

Thick Nickel Plating. D. Chambaud. (Mécanique, 1946, vol. 30, Dec., pp. 285–289). The electrodeposition of thick nickel coatings and their properties and uses are described.—R. F. F.

Repairing Motor Shafts by Nickel Deposition. W. O. Andrews. (Journal of the South African Institution of Engineers, 1947, vol. 46, Oct., pp. 44–58). A detailed account is given of a technique used for repairing worn air-fan shafts for power-station boilers by the electrodeposition of nickel.—C. O.

Factors to Consider in Hot Dip Galvanizing. A. D. Wilcox. (American Gas Association: Industrial Heating, 1947, vol. 14, Sept., pp. 1426–1430, 1458; Nov., pp. 1812–1820, 1856). Data on the consumption of zinc in hot-dip galvanizing are presented and the design of kettles and methods of heating them are discussed.——R. A. R.

Metallography of Hot-Dipped Galvanized Coatings. D. H. Rowland. (American Society for Metals, 1948, Preprint No. 18). A new metallographic etching reagent for galvanized coatings has been developed. With this reagent it is demonstrated that the "alloy layer" of galvanized coatings, both experimental and commercial, contains all of the phases shown by the Schramm iron–zinc constitution diagram at the temperature

level of commercial coating practice. Thickness measurements, and microhardness values of the various phases are presented. "Alloy layer" structures of coatings made from aluminium-bearing spelter are discussed. —R. A. R.

The Galvanizing of Steel Tubes. A. Gordet. (Métallurgie, 1947, vol. 79, July, pp. 19–20). Some practical aspects of the hot galvanizing of steel tubes are outlined. —J. C. R.

Regalvanizing of Welded Joints. G. H. Ohmer. (Corrosion, 1947, vol. 3, Nov., pp. 580–584). A process is described for regalvanizing areas on galvanized structures where the initial zinc coating has been destroyed by welding. The area to be recoated is heated to about 600° F. and rubbed with a stick of zinc alloy which melts at 460° F. Various mechanical tests on recoated steel specimens indicate that a good bond is obtained.—R. A. R.

A Step towards the Elimination of Tin in the Manufacture of Food Containers. The Mixed Container. P. Rocquet. (Métaux, Corrosion, Usure, 1942, vol. 17, Sept., pp. 160–162). The advantages of using tinplate for food containers, and its corrosion-resistance are reviewed. In order to economize in the use of tin in France in wartime, tinplate was used only for the sides of containers, the ends being of iron coated with a varnish having the greatest possible resistance to the action of acid juices.—J. C. R.

The Protection of Steel by Various Non-Metallic Coatings. J. C. Hudson and T. A. Banfield. (Journal of The Iron and Steel Institute, 1948, vol. 150, Jan., pp. 99–110).

Report on Investigations of Methods of Gaseous Metal Treatment. (British Intelligence Objectives Sub-Committee, 1948, Final Report No. 1535 : H. M. Stationery Office). Details are given of diffusion processes developed in Germany for impregnating steel surfaces with either aluminium or silicon. The experiments were sufficiently promising to justify ordering plant for small-scale production.—R. A. R.

Electrodeposition of Tungsten Alloys on Metal Surfaces. (Steel, 1947, vol. 121, Dec. 29, pp. 63–66). A procedure developed by the National Bureau of Standards for depositing a cobalt–tungsten alloy on steel is described. —R. A. R.

Electrodeposition of Tungsten Alloys Containing Iron, Nickel, and Cobalt. A. Brenner, Polly Burkhead and Emma Seegmiller. (Journal of Research of the National Bureau of Standards, 1947, vol. 39, Oct., pp. 351–383). Methods of depositing alloys of tungsten with metals of the iron group have been developed as a result of lengthy and comprehensive research, and determinations of some of the properties of the alloys indicate that the latter might be of commercial value. The nickel and the cobalt alloys have a hardness of 350–700 Vickers in the as-plated conditions, the hardness of the iron alloy being 700–900 Vickers; the cobalt–tungsten alloys retain their hardness when hot.—J. R.

Cleaning and Phosphate-Coating Home Appliances at Hotpoint, Inc. N. P. Gentieu. (Products Finishing, 1947, vol. 12, Dec., pp. 16–24). Surface-cleaning and phosphate-coating methods used at the works of Hotpoint, Inc., in the production of domestic electric water heaters and electric ranges are outlined as examples of the craftsmanship employed in the manufacture of ordinary household electric appliances.—J. R.

Metal Spray Practice in Steel Plants. A. E. Cichelli. (Iron and Steel Engineer, 1947, vol. 24, Dec., pp. 35–47). Methods and apparatus are described for the building-up of worn heavy metal parts by the deposition of atomized metal sprayed from a wire pistol. Examples of steelworks equipment renewed by the process are illustrated.—J. R.

The Fuse-Bond Process—Principles and Applications. J. Porter. (Welding, 1947, vol. 15, Dec., pp. 568–572). A short description is given of the Fuse-bond process for preparing metal surfaces for metallizing. Alloy welding electrodes, with a high current and low voltage are stroked lightly over the surface to be prepared. The high contact resistance causes the melting of the electrode tip, and small particles to vaporize, giving a discontinuous arc and a sputter of metallic foam, which adheres to the base metal, but has a very rough upper surface.—C. O.

Phosphatization as Protection against Corrosion. J. H. Frydlender. (Revue des Produits Chimiques, 1946, vol. 48, Oct. 15–31, pp. 171–175). Phosphatization as protection against corrosion is reviewed.—R. F. F.

Zinc Chromate or Zinc Yellow. New Protective Pigment. J. Frydlender. (Revue des Produits Chimiques, 1946, vol. 48, Jan. 15–31, pp. 1–7). The composition, properties, and uses of zinc yellow anti-corrosion paint and its manufacture are reviewed.—R. F. F.

Use of Zinc Yellow or Zinc Chromate for Protection against Corrosion. J. H. Frydlender. (Revue des Produits Chimiques, 1946, vol. 48, Dec. 15–31, pp. 209–212). This is Part 5 of an article reviewing recent progress in paint manufacture; it deals with anti-corrosion paints, in particular zinc-yellow paints.—R. F. F.

Use of Red Lead and Zinc Yellow in Anti-Corrosion Paints. J. H. Frydlender. (Revue des Produits Chimiques, 1947, vol. 49, Mar. 15–31, pp. 40–41). The production and properties of red lead and zinc yellow as anti-corrosion paints are compared.—R. F. F.

Notes on the Corrosion, Fouling and Protection of Keels. H. Masseille. (Peintures, Pigments-Vernis, 1947, vol. 23, Aug., pp. 231–235). Fouling and corrosion of hulls and anti-fouling paints and protective coatings are discussed.—R. F. F.

Protection of Ships' Hulls against Corrosion, and Anti-Fouling Paints. F. Fancutt and J. C. Hudson. (XXe Congrés de Chimie Industrielle : Peintures, Pigments-Vernis, 1947, vol. 23, Oct. pp. 292–301; Nov., pp. 332–341). The work of the Marine Corrosion Sub-Committee of the Corrosion Committee of the Metallurgy (General) Division of B.I.S.R.A. is described and the properties and composition of anti-fouling paints are discussed.—R. F. F.

Apparatus for the Rapid Measurement of the Thickness of Coatings. J. J. Frillat and H. Gervais. (Peintures, Pigments-Vernis, 1947, vol. 23, Dec., pp. 365–367). An apparatus for the measurement, with an accuracy of 0·01 mm., of the thickness of non-magnetic coatings deposited on magnetic metals is described. The force required to lift a magnetized bar from the surface of the coated metal is determined.—R. F. F.

Studies on Anti-Fouling Compositions. Part I—General Introduction. H. Barnes. (Journal of The Iron and Steel Institute, 1947, vol. 157, Dec., pp. 587–590).

Studies on Anti-Fouling Compositions. Part II—The Formation of Copper Soaps in the Preparation of Compositions Containing Cuprous Oxide and Rosin. H. Barnes. (Journal of The Iron and Steel Institute, 1947, vol. 157, Dec., pp. 590–593).

Studies on Anti-Fouling Compositions. Part III—The Rate of Loss of Material from a Graded Series of Varnishes Exposed in the Sea. H. Barnes. (Journal of The Iron and Steel Institute, 1947, vol. 157, Dec., pp. 593–600).

POWDER METALLURGY

Furnace Atmospheres for Sintering. Part IV. Gas Analyzers. H. M. Webber and A. G. Hotchkiss. (Metal Powder Association : Industrial Heating, 1947, vol. 14, Oct., pp. 1618–1622, 1654–1656). Apparatus for testing the properties and purity of protective atmospheres used in the sintering of metal powders are described.—R. A. R.

Proceedings of the Third Annual Spring Meeting of the Metal Powder Association. (Metal Powder Association, New York, 1947). The Third Annual Spring Meeting of the Metal Powder Association was held in New York on May 27, 1947. Abstracts of the papers which were presented follow.—C. O.

Stainless Steel Powder. J. D. Dale. (*Ibid.*, pp. 4–11). Details are given of compaction and sintering tests made during the development of a commercial low-carbon 18/8 stainless-steel powder, produced by the disintegration of massive alloy along its grain boundaries. Applications of the powder include the manufacture of filters and powder spraying.—C. O.

New Developments in the Production of Metal Powder Parts. E. E. Ensign. (*Ibid.*, pp. 14–20). An account is given of the development of a process for the production from iron powder of an oil-pump gear. The powder mixture (90 parts iron, 10 parts copper, 1·2 parts stearate) is pressed to form a blank with a density of 5·5 g./c.c., sintered at 2040° F. for 20 min. in a continuous electric furnace, cooled, dipped in lubricating oil, and coined. The coining determines all the finished dimensions except the length, which is corrected by grinding. The tools used in the coining operation are described.—C. O.

Cost Calculation in the Production of Powder Metallurgy Parts. D. H. Hausner. (*Ibid.*, pp. 21–29). The author analyses the cost of production of an engineering component made from iron powder. He shows that the overhead costs are very high compared with the cost of the raw material, and considers that the present high price of the latter can to a great extent be offset by operating plant at peak capacity.—C. O.

Bearings, Bushings and Allied Products. A. J. Langhammer. (*Ibid.*, pp. 32–34). The advantages of powder metallurgy for the manufacture of bearings are briefly discussed.—C. O.

Apparatus for Air Classification of Metal Powders. E. C. Truesdale. (*Ibid.*, pp. 35–50). A detailed description is given of a laboratory instrument for the classification of sub-sieve sizes of metal powders. The instrument, based on the principle of air elutriation according to Stokes' Law, has been found capable of accurately fractionating spherical particles up to 40 μ in dia., and to give reproducible results for non-spherical particles (other than flakes) up to 75 μ in dia.—C. O.

Copper–Lead Bearings from Metal Powder. E. R. Darby. (*Ibid.*, pp. 52–54). A short account is given of the manufacture of steel-backed copper–lead lined bearings for internal-combustion engines. The copper–lead powder mixture (20–45% Pb) is spread on steel strip, heated in a controlled-atmosphere furnace, and compacted by rolling.—C. O.

Electrical and Electronic Components from Powdered Metals. E. I. Shobert, II. (*Ibid.*, pp. 57–66). The applications of metal powders in the manufacture of electrical contacts, metal–graphite brushes, permanent magnets, soft magnetic materials, and high-frequency iron cores are discussed.—C. O.

Metal Powders as Pigments. E. Scheller. (*Ibid.*, pp. 67–68). The use of metal powders as pigments in paints is very briefly discussed.—C. O.

The Economy of Production of Structural Parts by Powder Metallurgy. H. W. Fischer and R. P. Seelig. (Powder Metallurgy Bulletin, 1947, vol. 2, Nov., pp. 128–134). The various processes and operations in the production of structural parts are analysed from the point of view of costs. A notable feature is the present high level of overhead costs : this will decrease with increased demand and production.—M. A. V.

The Theoretical Bases of Fritting Processes in Powders. G. F. Hüttig. (Iron and Steel Institute, 1948, Translation Series, No. 332). This is an English translation of a paper which appeared in Metallwirtschaft, 1944, vol. 23, Oct. 20, pp. 367–372. The author discusses the behaviour of an isolated single crystal subjected to gradually increasing temperature, with explanations of diffusion in the interior and at the surface. The fusion of two homogeneous crystallites in contact at gradually rising temperature is studied and divided into seven periods each characterized by the phenomena occurring in its particular range of temperature. Finally, curves are presented showing the changes in such properties as bulk density, adsorption capacity, volume of capillaries, moisture content, strength, hardness, and electrical resistance of metal and metal-oxide powders as they are slowly and steadily heated through these seven periods.—R. A. R.

Powder Metallurgy. W. D. Jones. (Metal Industry, 1948, vol. 72, Jan. 9, pp. 23–24). This is a review of developments during 1947 in the preparation, manufacture, and testing of metal powders. Twenty-eight references to the published literature are included.—R. E.

Progress in Powder Metallurgy. E. J. Sandford. (Metallurgia, 1947, vol. 37, Dec., pp. 95–99). A critical review is made of the literature dealing with powder-metallurgy processes and applications, and possible future trends are discussed. It is considered that, in general, competition with alloys produced by normal metallurgical methods depends on the physical properties of the powder-metallurgy products ; if future processes are based on cold pressing some of these properties could be improved by increasing the compacting pressure above the limit at present considered practical.—J. R.

Production Processes—Their Influences on Design. Part XXVII—Powder Metallurgy. R. W. Bolz. (Machine Design, 1947, vol. 19, Sept., pp. 139–146). General considerations in the design of parts to be produced by powder metallurgy are outlined.—C. O.

Carbonyl Nickel and Carbonyl Iron Powders, Their Production and Properties. (British Intelligence Objectives Sub-Committee, 1947, B.I.O.S. Final Report No. 1575 : H.M. Stationery Office). Statistical and technical information on German production is given. Brief details are included on the production of nickel-iron powders, cobalt, cobalt carbonyl, molybdenum carbonyl, and tungsten carbonyl.

Powder Metallurgy. H. W. Greenwood. (Metal Industry, 1947, vol. 71, Dec. 26, pp. 579–520). This is a brief discussion of the importance of powder metallurgy in the development of wear-resistant and temperature-resistant metals and alloys.—R. E.

The Reactivity of Solid Materials and Its Significance in Powder Metallurgy. J. A. Hedvall. (Archiv für Metallkunde, 1947, vol. 1, July–Aug., pp. 296–298). Factors affecting the reactivity of solids are discussed and examples are taken from the literature to show that the surface activity of materials can be appreciably

affected not only by heat but also by electrical and magnetic factors, radiation, and supersonic vibration.—R. A. R.

The Solubility Law in Powder Metallurgy. H. Umstätter. (Archiv für Metallkunde, 1947, vol. 1, July–Aug., p. 299). It is shown that materials such as metals will form solid solutions the more readily as the frequencies of their thermal molecular vibrations approach coincidence.—R. A. R.

PROPERTIES AND TESTS

Methods Used in the Preparation of Test Specimens. G. L. Smith. (Sheet Metal Industries, 1947, vol. 24, Aug., pp. 1609–1614; Sept., pp. 1809–1814, 1824; Nov., pp. 2245–2247, 2262; Dec., pp. 2444–2446, 2450). A review is made of the methods used in a laboratory dealing with problems involved in the production of steel and steel tubes for the preparation of macro- and micro-specimens and the common types of test-pieces when required in batches.—C. O.

Note on the Temperature Variation of Young's Modulus of Various Steels. F. W. Jones and J. Nortcliffe. (Journal of The Iron and Steel Institute, 1947, vol. 157, Dec., pp. 535–536).

Influence of Metallurgical Factors on the Mechanical Properties of Steel. S. A. Herres and C. H. Lorig. (American Society for Metals, 1948, Preprint No. 20). Data are presented to illustrate the individual influences of the following metallurgical conditions on the strength and toughness of steel: Non-metallic inclusions, austenite decomposition products, austenite grain-size, and various precipitations which occur during tempering.—R. A. R.

Study of the Variations in Results of Tensile Tests on Pearlitic Grey Cast Irons. P. Bastien and L. Beugras. (Comptes Rendus, 1947, vol. 224, May 12, pp. 1330–1332). Tensile tests were carried out at varying speeds on test-pieces of pearlitic cast iron having a cylindrical or a threaded head. In the former case results varied more widely as the speed of loading increased, but with the threaded head the results were grouped according to Gauss' law. It is concluded that for a given speed of solidification, the tensile test is better adapted than torsional and static bend tests for determining the mechanical resistance of cast irons.—J. C. R.

Research on the Elastic Properties of Metals Using Two Pendulums in Resonance. C. Sălceanu. (Comptes Rendus, 1947, vol. 224, June 23, pp. 1756–1758). An account is given of an investigation of the elastic properties of metals by utilizing the phenomenon of resonance, two pendulums of equal length being joined by a wire of the metal being studied.—J. C. R.

Applications of the Resonant-Pendulum Method to the Estimation of the Coefficient of Rigidity of Metals. C. Sălceanu. (Comptes Redmus, 1947, vol. 224, June 30, pp. 1810–1811). Details are given of tests on eight metals including iron and steel. The effect of temperature was also noted and it was considered that by this method useful information on the modification of the elastic nature of metals subjected to heat-treatment, might be obtained.—J. C. R.

Influence of Surface Straining of the Test-Piece on the Internal Stresses in Steel. C. Boulanger. (Comptes Rendus, 1947, vol. 224, Feb. 24, pp. 566–568). The author describes the relatively great effect of slight surface straining on the internal stress of a test-piece of self-hardening chromium–molybdenum–nickel steel with a bainitic structure. The tests were carried out with a Coulomb micro-pendulum appliance.—J. C. R.

Fluidity Test for Steel. E. Tallec. (Fonderie, 1946, Apr., pp. 156–158). An account is given of the Gabino spiral test for determining fluidity, and the results obtained are compared with those from the Cury test.—J. C. R.

Statistical Study of the Variations in Elasticity of a Cast Basic Electric Mild Steel. P. Bastien and L. Alanore. (Société Française de Métallurgie, 1946, vol. 43, Nov.–Dec., pp. 289–296). Tests were carried out on 133 specimens of electric-furnace steel divided into the following groups in accordance with their manganese contents: (1) Mn $>$ 0·650%; (2) Mn. 0·650–0·700%; (3) Mn 0·700–0·800%; and (4) Mn $\geqslant$ 0·800%. The object was to determine the influence of sulphur, phosphorus, manganese, carbon, and silicon. The variation in elasticity in relation to mechanical resistance was also determined.—R. F. F.

Distribution of Strength and Ductility in Welded Steel Plate as Revealed by the Static Notch Bar Tensile Test. W. F. Brown, jun., L. J. Ebert, and J. Sachs. (Welding Journal, 1947, vol. 26, Oct., pp. 545-s–554-s). The results of an investigation, by means of the static notched-bar tensile test, of the distribution of mechanical properties in 1-in. thick Unionmelt butt-welded low-carbon firebox-steel plates are presented. Among the conclusions reached are: (1) A hardness survey is a useful indication of the extent of the heat effect, but hardness is not a criterion of ductility; (2) variations in the strength and ductility of arc-welded carbon-steel plates at room temperature can be detected by means of eccentric and concentric notched-bar tensile tests; (3) two zones of low ductility may be present in hand-welded plates, but no appreciable variation in ductility is found in machine-welded plates; (4) a stress-relief treatment at 150° F. for 1 hr. restores the ductility in the embrittled zones; and (5) the large variations in material encountered make difficult the interpretation of the notched-bar properties in terms of welding effects.—C. O.

Effects of Section Size on the Static Notch Bar Tensile Properties of Mild Steel Plates. W. F. Brown, jun., J. D. Lubahn, and L. J. Ebert. (Welding Journal, 1947, vol. 26, Oct., pp. 554-s–559-s). The influence of section size on the results of static notched-bar tensile tests on 0·25% carbon steel plate, fully killed with silicon, has been investigated. A decrease in tensile strength from 110,000 lb./sq. in. for a specimen $\frac{1}{4}$ in. in dia. to 88,000 lb./sq. in. for a specimen 4 in. in dia. was found. The corresponding decrease in ductility was from 20% to 2%. The data obtained by the authors are compared with those of other workers, and possible explanations of the size effects are discussed.—C. O.

The Weld Bead Bend Test. W. P. van den Blink. (Lastechniek, 1947, Dec., pp. 123–124). [In Dutch.]

Metallurgical Factors in the Embrittlement of Welded Plate. R. D. Stout and L. J. McGeady. (Welding Journal, 1947, vol. 26, Nov., pp. 683-s–692-s). An investigation of the causes of the embrittlement of welded $\frac{3}{4}$-in. steel plates is reported in which the longitudinal notch bend test was used to study the initiation and growth of cracks. The cracks originated in the coarse grains at relatively small deformations, and were intergranular. The beneficial effect of post-heating was demonstrated.—R. A. R.

Brittleness of Steel after Pickling. P. Bastien. (Métaux, Corrosion, Usure, 1942, vol. 17, Oct., pp. 177–181; Nov., pp. 199–208, 214). The following aspects of the pickling embrittlement of carbon steels are considered: The influence of composition on the brittleness resulting from pickling; the influence of the nature, composition and temperature of the pickling bath; the development of pickling embrittlement in relation to the surrounding media and the condition of the metal; the influence of

the structural state of the steel; the action of pickling inhibitors on brittleness; and, electrolytic pickling.—J. C. R.

Lateral Vibration and Stress in a Beam Under Shock Machine Loading. E. G. Fischer. (Proceedings of the Society for Experimental Stress Analysis, 1947, vol. 5, pp. 78–89). The author applies the methods of the operational calculus to solve the equation for the lateral vibration of an elastic bar the hinged ends of which are subjected to motions in typical shock-testing machines.—R. A. R.

High-Temperature Strain Gages and Their Application to Measurement of Vibratory Stresses in Turbosupercharger Buckets. S. S. Manson, R. H. Kemp, and W. C. Morgan. (Proceedings of the Society for Experimental Stress Analysis, 1947, vol. 5, pp. 90–100). A description is given of a method of constructing, mounting, and testing strain gauges that can withstand a temperature of 1500° F. The application of the strain gauges to the measurement of vibratory stresses in the buckets of a modified turbosupercharger is also dealt with.—R. A. R.

Calculating Hoist Rope Stresses. L. Sanderson. (Mine and Quarry Engineering, 1947, vol. 13, Nov., pp. 344–346; Dec., pp. 375–376). Some of the factors to be taken into consideration in calculating the stresses in winding ropes are discussed.—R. E.

Izod, Tensile and Hardenability Tests on S.A.E. 4140 Chromium-Molybdenum Steel. F. G. Lewis. (Australian Council for Scientific and Industrial Research, Division of Aeronautics, Report S.M. 75, Aug., 1947). The results of Izod, tensile, hardness and hardenability tests and metallographic examination of specimens of S.A.E. 4140 steel in the as-rolled, normalized, and oil-quenched and tempered conditions are presented. Low notched-bar impact strength was obtained in the as-rolled and normalized specimens, associated with a microstructure of free ferrite and intermediate transformation products; high impact strength was associated with uniform sorbitic structures in the quenched and tempered specimens. The Izod values were practically independent of testing temperature in the range −50° to + 50° C., except for a specimen oil-quenched at 850°, and tempered at 530° C., which showed a transition range between − 50° and + 25° C.—C. O.

The Practical Significance of Notched-Bar Impact Tests. A. R. Edwards. (Australian Council for Aeronautics, Reports A.C.A.-1 to 12, 1944, Report A.C.A.-6). This report comprises a study of the published data on the practical value of the notched-bar test so that a decision could be made whether or not the insertion of notched-bar figures in the specifications for Australian aircraft steels was justified. The bibliography contains 225 references. The use of the test in the routine examination of service failures was recommended, and the inclusion of the test in specifications was approved by the majority of those who compiled the report.—R. A. R.

Stresses in a Notched Strip under Tension. Chih-Bing Ling. (Journal of Applied Mechanics, 1947, vol. 14, Dec., pp. A-275–A-280). Although some approximate methods may have been used previously to calculate the stresses in a notched strip with or without the aid of photo-elastic observations, no theoretical solution seems to have been developed. The author has now formulated such a solution for a strip under tension; the strip being notched by a pair of symmetrical semi-circular arcs on its boundaries. Numerical examples of the solution have been worked out and compared with available experimental results.—R. A. R.

Influence of Foundry Factors on the Forgeability of Alloys. P. Bastien. (Fonderie, 1946, Mar., pp. 99–109). The following factors are considered in their relation to the forgeability of alloys. Crystal structure of the alloy; segregations and impurities; and variations of the volume and of the gases evolved during solidification and cooling.—J. C. R.

Forgeability Tester for Steels and Test Results. R. Canard. (Revue de Métallurgie, 1946, May-June, pp. 156–161). A laboratory apparatus to test the forgeability of steels at various temperatures, and the test-pieces used, are described. The apparatus is essentially an impact-tensile testing machine. Results of tests on certain steels are given.—R. F. F.

The Wire Resistance Strain Gauge. P. Savic. (Research, 1947, vol. 1, Dec., pp. 98–106). The theory, construction, and use of the wire electrical-resistance strain gauge are described.—C. O.

Method of Obtaining the Stress at the Mid-Thickness by Measurements from Only One Surface of a Plate. A. Boodberg and E. D. Howe. (Proceedings of the Society for Experimental Stress Analysis, 1947, vol. 5, pp. 56–58).

Criterion of Static and Fatigue Failures. A. Sniderman. (Proceedings of the Society for Experimental Stress Analysis, 1947, vol. 5, pp. 26–30). This paper deals with the problem of calculating permissible stresses for parts subjected to combined static and fluctuating loads.—R. A. R.

Interpretation of Results of Rotary Bending Fatigue Tests. J. de Lacombe. (Société Française de Métallurgie: Revue de Métallurgie, 1946, vol. 43, Sept.–Oct., pp. 271–285: Iron and Coal Trades Review, 1947, vol. 155, Dec. 5, pp. 1087–1090). Factors affecting the scatter of fatigue-test results are considered. It is concluded that the fatigue limit as determined by such results is correct only within 5–15%, and that a large number of tests must be carried out on any one steel to determine the approximate boundaries of the scatter. With hardened and tempered steels, inclusions of a few hundreths to one-tenth of a millimetre in diameter did not appear to reduce the fatigue limit by more than 10%.—R. A. R.

A New Apparatus of Czechoslovakian Construction for Measuring Hardness. J. Dobrý. (Hutnické Listy, 1947, vol. 1, No. 8, pp. 177–180). [In Czech]. A description is given of a diamond-pyramid hardness tester, of light and portable design with which loads in the 10–30 kg. range can be applied.—R. A. R.

Machine Design's Materials Work Sheet—Standard Steels, Wrought AISI Types, Part II. (Machine Design, 1947, vol. 19, Nov., pp. 151–163). The hardenability-band limits for the 1300*H*, 2500*H*, 3100*H*, 3300*H*, 4100*H*, 4300*H*, 4600*H*, 4800*H*, 5100*H*, 6100*H*, 8600*H*, 8700*H*, and 9200*H* series of steels are tabulated and the latest tentative S.A.E.-A.I.S.I. hardenability-band charts are presented.—C. O.

The Micro-Sclerometer: A New Micro-Hardness Tester. R. Girschig. (Revue de Métallurgie, 1946, vol. 43, Mar.–Apr., pp. 95–112: Metallurgia, 1947, vol. 36, Sept., pp. 269–273).

Contribution to the Question of Temper Brittleness of Steel. F. Pobořil and V. Koželev. (Hutnické Listy, 1946, vol. 1, No. 5, pp. 97–101; No. 6, pp. 130–133). [In Czech].

Temper-Brittleness of Chromium, Molybdenum and Tungsten Steels. G. Vidal. (Revue de Métallurgie, 1945, vol. 42, May pp. 149–155). As a result of tests on three steels containing: 1·4% of chromium, 2% of molybdenum, and 3·8% of tungsten respectively, it was concluded that tungsten and molybdenum steels are as susceptible to temper-brittleness as chromium and manganese steels.—R. F. F.

How to Measure Surface Roughness of Castings. G. Hobman. (Machinist, 1947, vol. 91, Dec. 6, pp. 1102–1103). A description is given of the Hobman-Meehanite Surface Meter for measuring the roughness of castings. It consists of a tripod support with a feeler needle directly connected to a dial gauge. The needle is mounted on a disc graduated so that the operator can move the former in 0·01-in. steps in a circle of 0·5 in. periphery. The dial gauge is marked in 0·0001-in. divisions.—R. A. R.

Measurement in Machinability Research. O. Svahn. (Conference on Instruments and Measurements, Stockholm, 1947: Machinist, 1947, vol. 91, Nov. 22, pp. 1029–1033). Methods used in tests of cutting, shearing, and plastic forming for measuring tool life, cutting and shearing forces, tool temperatures, and tool-surface finish are briefly outlined.—C. O.

Ductility of Steels for Welded Structures. A. B. Kinzel. (Campbell Memorial Lecture: Metal Progress, 1947, vol. 52, Nov., pp. 795–799). The author considers that the real criterion of weldability is ductility of the weldment. He outlines the service conditions which should be simulated in a laboratory test for the quantitative assessment of the ductility of welds, and describes the development of such a test—a notched-bead slow-bend test. The results of several thousand determinations of the ductility of fifteen commercial and nine experimental steels are presented, and the effects of temperature, velocity of testing, and degree of restraint are discussed.—C. O.

The Magneto-Elastic Constant of a 25% Chromium-Iron Alloy. O. Rüdiger. (Metallforschung, 1947, vol. 2, Sept., pp. 270–275).

The Relationship of Ferro-Magnetic Properties to Temperature as a Basis for Research on the Physical Properties of Metals. W. Gerlach. (Metallforschung, 1947, vol. 2, Sept., pp. 275–280). A critical review is presented of the author's and other test data on the relationship between magnetic saturation and temperature. The percentage remanence is independent of temperature when no change in structure takes place. All ferromagnetic materials have the same temperature relationship at above $T/\theta = 0 \cdot 6$. At below this temperature H_c for nickel crystals falls rapidly, whilst for nickel–gold alloys and sintered nickel it rises rapidly.—R. A. R.

Metal Loss and the Periodic System. K. Wickert. (Archiv für Metallkunde, 1947, vol. 1, June, pp. 278–281). The metals are grouped within the periodic system in accordance with their electron-receiving and electron-emitting properties.—R. A. R.

Interpretation of High Coercivity in Ferromagnetic Materials. E. C. Stoner and E. P. Wohlfarth. (Nature, 1947, vol. 160, Nov. 8, pp. 650–651). A brief account is given of a new theory to interpret the coercivity of ferromagnetic alloys with coercivities greater than 500 oersted. The basis of the theory is that in many ferromagnetic materials "particles" (powder grains and atomic aggregates or "islands" in alloys) may exist, which are distinct in magnetic properties from the general matrix, and less than the critical size for which domain-boundary formation is possible.—C. O.

Experimental Study of Metallic Diffusion by the Thermomagnetic Method Applied to Multilamellar Aggregates. P. Chevenard and X. Waché. (Revue de Métallurgie, Mémoires, 1944, vol. 41, Nov., pp. 353–368; Dec. pp. 389–402). If the Curie point of a ferromagnetic solid solution is a rapidly varying function of temperature, any defect of homogeneity will be revealed on a magnetization/temperature curve. From the temperature interval between the lowest and highest Curie points the deviation of the extreme concentrations from solid solutions can be calculated—the amplitude of heterogeneity can be expressed in figures. The extent can be represented by the area contained between the thermomagnetic curves for the heterogeneous and the homogenized alloy.

This method was used to study the secondary heterogeneity accompanying the dissociation when tempering hyperquenched iron–nickel–chromium–carbon solid solutions. It appeared to be first of all a trouble preceding any precipitation of carbide; a centripetal migration of chromium and carbon towards certain "privileged" points results in the formation of grains of carbide which, in developing, surround themselves with auras impoverished in carbon and chromium; these auras, in turn, vanish under the effect of diffusion which tends to make the composition of the austenite uniform.

This paper is divided into four chapters. The first, a review of theories relating to diffusion and methods of investigation, deals with the coefficient of diffusion and Fick's law, as applied to infinite cylinders and multilamellar aggregates, and compares experimental methods for the study of diffusion, indicating the advantages of the thermomagnetic method. The second chapter is concerned with the experimental technique employed. The multilamellar specimens were made by welding together under non-oxidizing conditions, piles of interleaved clean thin metallic sheets of different compositions and then cold-rolling the pile to one-quarter of the original thickness. Four pairs of materials were used: (*a*) two ferronickels (Ni 33% and 72½%), (*b*) two other ferronickels (Ni 37¾% and 49%), (*c*) nickel (99½%) and a paramagnetic alloy (iron-rich Ni 22½%, Cr 2%) and (*d*) a paramagnetic alloy (Baros) Ni 91½%, Cr 6¾%) and the iron-rich nickel alloy. A full account is given of the homogenizing, annealing and the evaluation of the duration of annealing, and of the micrographic and micromechanical examination of the multilamellæ after homogenization. The thermomagnetic study was carried out in an instrument in which the magnetization of the specimen was measured by the attraction exerted by a standard magnet. The specimen was held in one arm of a balance; at the other end was a mirror so that the vertical movement of the balance could be registered by a beam of light reflected from the mirror. A dilatometer alongside the specimen deflected the mirror laterally, so that the temperature of the specimen was indicated by the horizontal movement of the light beam.

The third and fourth chapters are concerned with the presentation and discussion in detail of the results obtained, and cover the definition and measurement of an index of heterogeneity and its variation with the time of annealing, a comparison of the practical results with theoretical forecasts, the determination of the heat of diffusion, a study of diffusion by the displacement of the highest Curie point, the determination of the coefficient of diffusion, the influence of temperature on the rate of diffusion, and the influence of temperature on the rate of diffusion and the accelerating effect of carbon.—A. E. C.

Supersonic Examination of Materials. B. Carlin. (Machinist, 1947, vol. 91, Dec. 20, pp. 1153–1158: Product Engineering, 1947, vol. 18, Oct., pp. 113–118).

Damping Capacity. F. C. Thompson. (Revue de Métallurgie, 1945, vol. 42, Apr., pp. 105–124). Damping capacity is studied and the effects of ferromagnetism, various metallographic factors, and frequency of vibrations on damping are discussed. Apparatus and methods of measuring and testing damping capacity are described. A bibliography is appended.—R. F. F.

The Damping Capacity of Steel and Alloys. E. M. A. Harvey. (Teknisk Tidskrift, 1947, vol. 77, Dec. 13, pp. 933–934). [In Swedish]. The influence of several factors on the damping capacity of steel and alloys is discussed. These factors include oscillation *in vacuo*, changes in carbon content and nickel content, cold-work, and heat. Data showing the relation between damping and magnetic properties under different conditions are presented.—R. A. R.

Creep of Steels at Room Temperature. F. Campus. (Revue Universelle des Mines, 1947, series 9, vol. 3, No. 12, pp. 595–605). The author describes an apparatus and a method for the determination of creep. Apparatus for the determination of relaxation is also described. The accuracy of the apparatus and methods are discussed and some results given.—R. F. F.

Cast Iron and Steel. E. C. Pigott. (Iron and Steel, 1947, vol. 20, Feb., pp. 43–45; Mar., pp. 93–95; Apr., pp. 133–135; May, pp. 181–183; June, pp. 307–309; Sept., pp. 442–444; Oct., pp. 476–478; Nov., pp. 519–520). A detailed survey is made of the effects of the following constituents on the properties of cast iron and steel: Aluminium, arsenic, beryllium, boron, carbon, cerium, chromium, niobium, nitrogen, oxygen, phosphorus, selenium, silicon, sulphur, tantalum, tellurium, tin, titanium, tungsten, uranium, vanadium, zirconium, and zinc.—R. A. R.

Copper Additions, Contaminants—Effect on Mechanical Properties of Gray Cast Iron. K. E. Rose and C. H. Lorig. (American Foundryman, 1947, vol. 11, May, pp. 83–93). *See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 308.

Molybdenum in Ferrous Base Metals. G. Fitzgerald-Lee. (British Steelmaker, 1947, vol. 13, Nov., pp. 564–568). A short account is given of the use of molybdenum as an alloying element in cast iron and steels.—C. O.

Data Notes—Properties of Rolled Steel Joists. H. Gottfeldt. (Structural Engineer, 1947, vol. 25, Nov., pp. 507–514). Data, supplementary to those in engineering handbooks, on the properties of individual parts of rolled steel joists, are presented.—C. O.

Estimated Properties of Common Compositions of Hot-Rolled and Cold-Drawn Carbon-Steel Bars. (A.S.T.M. Bulletin, 1947, Oct., pp. 31–33).

Industrial Alloys. (Mechanical World, 1947, vol. 122, Oct. 17, pp. 385–390). A general review is made of the physical properties and engineering applications of the common types of steels.—C. O.

Industrial Alloys—II. Carburizing Steels. (Mechanical World, 1947, vol. 122, Nov. 14, pp. 495–499). An account is given of the types and properties of steels suitable for carburizing and nitriding.—C. O.

Selecting, Testing, and Fabricating Spring Materials. F. P. Zimmerli. (Society of Automotive Engineers: Materials and Methods, 1947, vol. 26, Sept., pp. 74–79: Steel, 1947, vol. 121, Aug. 11, pp. 78–79, 108, 128). The author gives an account of the properties of steels for flat springs, carbon and alloy spring steels, and copper and nickel alloys for springs, and discusses the hot-forming of springs.—C. O.

Austenitic Malleable Iron—A New Ferrous Material. C. K. Donoho. (Materials and Methods, 1947, vol. 26, Sept., p. 85). A very brief account is given of the properties and applications of a modified Ni-Resist type of cast iron, which after heating at 1800° F. for 2 hr., has a substantially austenitic matrix.—C. O.

METALLOGRAPHY

The Selection of Stainless Steels for the Chemical Engineering Industries. L. Rotherham. (Society of Chemical Industry, 1947, Preprint). The metallurgical considerations which influence the choice of stainless steels for chemical-engineering applications are discussed.—C. O.

Improved Image Illumination and Contrast with the Metallurgical Microscope. E. W. Taylor. (Journal of the Royal Microscopical Society, 1945, vol. 65, Parts 1–4, pp. 1–7). It is shown that when the illuminating arrangements necessitate the double passage of light through a microscope objective, it is most desirable that the surface of the lenses should be "coated" to reduce surface reflection and the presence of harmful light in the focal plane. When using a cover-glass illuminator, it is possible to increase the intensity of the image illumination as much as three times by suitably coating the surface of the cover-glass.—R. A. R.

Advances in the Design of the Inverted Prismatic Microscope. J. McArthur. (Journal of the Royal Microscopical Society, 1945, vol. 65, Parts 1–4, pp. 8–16). Improvements in the design of the prismatic microscope since its principles were made known in 1933 are described and the advantages claimed for it are discussed.—R. A. R.

The Electrolytic Polishing of Metals. G. Tolley. (Metallurgia, 1947, vol. 37, Dec., pp. 71–74). Electrolytic polishing of metals is a relatively recent development, but research on the subject has proceeded rapidly and has brought the technique to a high standard of efficiency. Laboratory and industrial methods and applications of the process are outlined.—J. R.

The Examination by Electronic Diffraction of Surfaces Obtained by Electrolytic Polishing. J. J. Trillat. (Comptes Rendus, 1947, vol. 224, Apr. 14, pp. 1102–1103). The diffraction of electrons by polished metal surfaces enables information to be gained on the structure of layers near the surface. Thin sheets of pure iron, aluminium and copper, previously treated with 000 or 0000 emery paper, were electrolytically polished in a perchloric-acetic bath or a phosphoric bath, and then carefully washed in distilled water and alcohol. The method of examination and the results obtained are described. The most noteworthy feature was the virtual disappearance of the Beilby layer.—J. C. R.

Macro-Etching and Photomacrography of Ferritic and Austenitic Welded Joints in Low-Alloy Steel. O. O. Miller and E. G. Houston. (Welding Journal, 1947, vol. 26, Oct., pp. 620-s–625-s). Procedures are described for macro-etching and photographing polished sections of welds made with ferritic or austenitic electrodes in low-alloy steel base metal. The photographing of fractured surfaces is also discussed.—C. O.

Notes on Elongated Inclusions. Platon. (Revue de Métallurgie, 1942, vol. 39, June, pp. 189–192). The relationship between small dots on the cross section of an ingot shown by the Bauman print and defects due to segregation is discussed.—R. F. F.

New Applications of X-Ray and Electron Beams to Metal Research. B. H. Alexander. (Metal Progress, 1947, vol. 52, Dec., pp. 989–990, 1024). A review is made of a series of papers presented at the Fifth Annual Pittsburgh Conference on X-Ray and Electron Diffraction at the Mellon Institute on Nov. 7 and 8, 1947. These dealt with the crystal structure of heat-resisting alloys; the design of X-ray and electron-diffraction cameras; a high-temperature X-ray diffraction camera; the structure of oxide films on copper and nickel; a modification of the "oscillating crystal" method for analysing two-dimensional diffraction effects from aged alloys; and adaptation of the Lonsdale divergent-beam technique; and interstitial compounds.

The Structure of Hot-Galvanized Coatings. H. Bablik, F. Götzl, and R. Kukaczka. (Iron and Steel Institute, 1948, Translation Series, No. 331). This is an English

translation of a paper which appeared in Korrosion and Metallschutz, 1945, vol. 21, No. 1/2, pp. 1–8. The author describes in detail the structure of hot-dip zinc coatings on steel showing the influence of the composition of the steel and the temperature of the bath. Over 40 micrographs are reproduced.—R. A. R.

Ferromagnetic Parameters and Grain Size. J. G. Koenigsberger. (Philosophical Magazine, 1947, vol. 38, Sept., pp. 640–657). The change of ferromagnetic parameters by alteration of grain-size is given to two significant figures, based on the observations of previous authors, and of the present author on single bodies of different sizes when other influences such as strain, were as far as possible removed.—R. A. R.

Detection of As-Cast Austenite Grain Size in Heat-Treated Cast Alloy Steels. E. A. Loria. (American Society for Metals, 1948, Preprint No. 28). This paper gives an account of a method of measuring the as-cast austenite grain-size in cast alloy steels by considering the effect of the solidification pattern and segregation of alloying elements on the development of the as-cast grain pattern.—R. A. R.

On the Crystallization of Alloys. J. Ternisien. (Métallurgie, 1947, vol. 79, Aug., pp. 9–12). This is a general article dealing with equilibrium diagrams, crystallization and structure of alloys, and structural hardening by quenching and tempering.—J. C. R.

Recrystallization in Deformed Metals. J. Ternisien. (Métallurgie, 1947, vol. 79, Sept., pp. 9, 11–12). The phenomena of primary and secondary recrystallization are reviewed.—J. C. R.

The Lattice Strength of Crystals and Metals as a Definite Fraction of the Elastic Modulus. J. Bingel. (Archiv für Metallkunde, 1947, vol. 1, July-Aug., pp. 300–304). The Madelung lattice potential and Born's electrostatic potential methods are applied to show that the strength of the ideal atomic lattice of face-centred cubic crystals is a definite fraction of the elastic modulus.—R. A. R.

Deoxidation Control by Fractography. G. C. Woodside. (Iron Age, 1947, vol. 160, Dec. 4, pp. 78–79). The evaluation of the forgeability of molybdenum ingots by examination of fractured surfaces is illustrated by a series of photographs. Brittle ingots are characterized by oxide films or dendrites in the grain boundaries.—C. O.

Principle of a Method for the Rapid Formation of Superlattices. Application to Platinum–Iron Alloys. L. Weil. (Comptes Rendus, 1947, vol. 224, Mar. 24, pp. 923–925). The author presents the results of his investigations on the structure of an iron–platinum alloy obtained by the reduction of potassium platinocyanide.—J. C. R.

A New Structural Diagram for Cast Iron. H. Laplanche. (Metal Progress, 1947, vol. 52, Dec., pp. 991–993). The Maurer structural diagram for cast iron is critically examined, and shown to be erroneous in two fundamentals—in having one diagram for all rates of cooling, and in assuming that the boundary lines are straight. The author has developed a new diagram, consisting of curves of "equal graphitizing tendency," calculated from a formula (based on experimental observations) for the effect on graphitization of carbon and silicon at fixed rates of cooling.—C. O.

INDUSTRIAL USES AND APPLICATIONS

Materials and Their Requirements for Automobile Stampings, Bumpers and Pistons. N. J. Meagley. (Materials and Methods, 1947, vol. 26, Nov., pp. 74–78). The requirements of metals intended for the production of automobile stampings, fenders, and engine pistons by pressing, hot-working, and casting, respectively, are described as examples of how the automobile industry takes such factors into consideration in the selection of materials and the methods of fabricating them.—J. R.

The Replacement of Tin in the Food Canning Industry. J. Bary and L. Kientz. (Métaux, Corrosion, Usure, 1942, vol. 17, Sept., pp. 163–164). A brief description is given of the manufacture of substitute food containers having the sides made from black plate and the ends of lacquered iron.—J. C. R.

Standardisation of Tool Steels in the U.S.S.R. (Courrier de la Normalisation No. 68-46 : Echo des Mines, 1947, Nov., pp. 196–197). The Russian standardization of tool steels is summarized under three main categories : plain carbon, high-speed, and alloy steels.—R. F. F.

Materials Used in High-Pressure Apparatus. P. Bastien. (Centre de Perfectionnement Technique : Chimie et Industrie, 1945, vol. 54, Sept., pp. 159–166). Steels used in the manufacture of high-pressure systems, are studied and classified under three main headings : Steels for use with cold non-corrosive fluids, with hot non-corrosive fluids, and with corrosive fluids.—R. F. F.

Refractory Heavy Metal Carbides. M. Oswald. (Chimie et Industrie, 1943, vol. 49, Jan., pp. 8–16). The preparation and metallography of the sintered carbides and their application for cutting tools and dies are described. The influence of cobalt on carbides is also discussed.—R. F. F.

Metallurgical Progress and the Mining Industry. L. Sanderson. (Mine and Quarry Engineering, 1947, vol. 13, Dec., pp. 367–369). This is a brief review of developments in the application of metals and alloys for mining equipment.—R. E.

Metallurgical Examination of Landing Wheel and Strut, Wing Sections and Components from Japanese Aircraft "Francis." (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1465 : H.M. Stationery Office).

Metallurgical Examination of Japanese Sakae-12, Engine No. 124676. (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1466 : H.M. Stationery Office).

Metallurgical Examination of Landing Gear Strut, Landing Wheel and Tail Wheel Strut Assembly from Japanese Aircraft "Betty." (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1482 : H.M. Stationery Office).

Metallurgical Examination of Two Japanese Oxygen Cylinders. (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1498 : H.M. Stationery Office).

Metallurgical Examination of a Japanese 15cm. Howitzer. (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1514 : H.M. Stationery Office).

Metallurgical Examination of Armor Plate from Japanese Aircraft "Betty." (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1519 : H.M. Stationery Office).

Metallurgical Examination of Armour Plate from Japanese Aircraft "Lily 2." (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1520 : H.M. Stationery Office).

Metallurgical Examination of Japanese ·30 Calibre and ·50 Calibre Disintegrating Cartridge Link Belts. (British Intelligence Objectives Sub-Committee, 1948, Report No. B.I.O.S./J.A.P./P.R./1522 : H.M. Stationery Office).

Metallurgical Examination of Sections of 15, 30 and 50 Kilogram Japanese Antipersonnel Bombs. (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1526 : H.M. Stationery Office).

Metallurgical Examination of Japanese 47mm. C/R/ H.E. U/F Shell for Model 1 A/T Gun. (British Intelligence Objectives Sub-Committee, 1948, Report No. B.I.O.S./J.A.P./P.R./1531 : H.M. Stationery Office).

Metallurgical Examination of a Japanese 57mm. Tank Gun, Model 97. (British Intelligence Objectives Sub-Committee, 1948, Report No. B.I.O.S./J.A.P./P.R./1535 : H.M. Stationery Office).

Metallurgical Examination of Parts from a Japanese Sakae 12 Engine. (British Intelligence Objectives Sub-Committee, 1948, Report No. B.I.O.S./J.A.P./P.R./1537 : H.M. Stationery Office).

Metallurgical Examination of Parts from an Aichi V-12 Japanese Aircraft Engine. (British Intelligence Objectives Sub-Committee, 1948, Report No. B.I.O.S./J.A.P./P.R./1538 : H.M. Stationery Office).

Metallurgical Examination of Japanese Navy 1-KVA Alternating Current Generator Repair Kit. (British Intelligence Objectives Sub-Committee, 1948, Report No. B.I.O.S./J.A.P./P.R./1541 : H.M. Stationery Office).

A Metallurgical Examination of a Japanese Four-Barrel Carburettor. (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1545 : H.M. Stationery Office). The throttle shaft and flow valve needle were of 13%-chromium steel. The valve was differentially hardened—448 Vickers hardness at the valve end and 240 at the stem end.—M. H. V.

Metallurgical Examination of Parts from a Japanese Mamoru-II Aircraft Engine. (British Intelligence Objectives Sub-Committee, 1948, Report No. B.I.O.S./J.A.P./P.R./1546 : H.M. Stationery Office).

HISTORICAL

Steelmaking Since 1870. T. M. Service. (West of Scotland Iron and Steel Institute : Iron and Steel, 1947, vol. 20, Nov. 20, pp. 547–550). In his presidential address to the West of Scotland Iron and Steel Institute the author discusses some of the advances made in steelmaking research and methods since 1870.—J. R.

Technical Developments in Ferrous Metallurgy. G. Grenier. (Revue de Métallurgie, 1945, vol. 42, Jan., pp. 1–6). The main developments in the manufacture of iron and steel from the time of the earliest manufacture of iron to the present day, are reviewed.—R. F. F.

A Problem of the Past Investigated. J. D. Aylward. (Edgar Allen News, 1948, vol. 26, Jan., pp. 977–980). The methods by which the elaborately decorated steel sword hilts of the past were produced are discussed. The writer considers that many of them were wrought, but that some were cast by the lost-wax process at an early stage in their manufacture.—C. O.

Sword Ornaments. J. D. Aylward. (Edgar Allen News, 1948, vol. 26, Jan., pp. 980–981). A short report is made on a metallographic examination of some eighteenth-century sword ornaments.—C. O.

The Origin of the Steel, Copper and Zinc Metallurgical Industries of the Liége District. M. Choul. (Métallurgie, 1947, vol. 79, Oct., pp. 7–9). A short account is given of the early iron, steel, copper, brass, and zinc industries in the Liége district.—J. C. R.

Is the Prehistoric Ring of Byčí Skála from Cast Iron ? V. Jareš. (Hutnické Listy, 1947, vol 2, No. 6, pp. 128–129). [In Czech]. The author presents evidence that this ring of the sixth century B.C. was not cast, but was drop-forged in dies in two halves and then fire-welded. (*See* Journ. I. and S.I., 1947, vol. 157, Nov., p. 478).—R. A. R.

Address on the 200th Anniversary of Jernkontoret. H. Silverstolpe. (Jernkontorets Annaler, 1947, vol. 131, No. 12, pp. 519–524). [In Swedish].

The Black Death of 1348–49 and Its Effect upon the Iron Industry. H. R. Schubert. (Journal of The Iron and Steel Institute, 1947, vol. 157, Dec., pp. 525–526).

ECONOMICS AND STATISTICS

Iron and Steel Production and Development. (Metallurgia, 1947, vol. 37, Dec., pp. 61–64). At a meeting held under the auspices of the University of London and the Institute of Bankers, R. M. Shone spoke of production and development in the iron and steel industry. The output achieved in 1947 exceeded that for 1946 and is especially noteworthy when the difficulties encountered are considered ; an even higher total is aimed at for 1948, when it is anticipated that about 13 million tons of steel will be supplied to the home market and that 1¾ million tons will be exported.—J. R.

The Outlook in Merchant Pig Iron. B. S. Stephenson. (Yearbook of the American Iron and Steel Institute, 1947, pp. 312–335). The past and present positions and the future outlook for the supply and demand for pig iron and ferro-alloys in the United States, not for maker's use, are reviewed, and statistics on production, imports, and exports, and blast-furnaces abandoned and constructed since 1936 are presented.—R. A. R.

World Wide Wire Industry—Australia. O. Semler. (Wire and Wire Products, 1947, vol. 22, Nov., pp. 898–899). Data on the production of ferrous and non-ferrous wire in Australia are presented and the position of the industry is reviewed.—R. A. R.

World Wide Wire Industry—Czechoslovakia. (Wire and Wire Products, 1947, vol. 22, Nov., p. 900). The development of the wire industry in Czechoslovakia is reviewed.—R. A. R.

World Wide Wire Industry—Germany. P. Fidrumuc. (Wire and Wire Products, 1947, vol. 22, Nov., pp. 903, 917). Data on the production of wire in Germany in 1946 are presented and the outlook is discussed.—R. A. R.

Reconstruction in the Norwegian Iron and Steel Industry. (Stahl und Eisen, 1947, vol. 66–67, Dec. 4, pp. 430–432). A Norwegian Government Commission has recently reported on the present position of iron and steel imports and requirements, and on the setting up of plants to make the country self-sufficient. The principal items of this report are outlined.—R. A. R.

Present Position and Future Prospects of the Polish Industry. (Chimie et Industrie, 1946, vol. 56, July, p. 64). Reference is made to the position of the Polish steel industry and plans for modernizing it.—R. F. F.

The Steel Industry's Public Relations Program. E. L. Ryerson. (Yearbook of the American Iron and Steel Institute, 1947, pp. 655–664). An outline is given of a large-scale publicity programme being undertaken by the Public Relations Committee of the American Iron and Steel Institute to convince the American people that : (1) The steel industry is rendering a vital service to the nation ; (2) the steel industry gives this service at a fair price, with a fair profit, a high degree of economic efficiency, and a deep sense of responsibility ; and (3) the steel industry is foremost in wages, working conditions, and research.—C. O.

The Future of the Steel Industry. W. Sykes. (Yearbook of the American Iron and Steel Institute, 1947, pp. 68–81). *See* Journ. I. and S.I., 1947, vol. 157, Nov., p. 478.

The Iron and Steel Control Association. (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1426 : H.M. Stationery Office). The organization of the Iron and Steel Control Association in Japan is discussed.—R. A. R.

Iron and Steel Metallurgy of the Japanese Empire. (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1432 : H.M. Stationery Office). An account is given of the economic development of the iron and steel industry of the Japanese Empire.—R. A. R.

Plan of British Manufacturers for the Reconstruction of the Iron and Steel Industry. K. Stein. (Hutnické Listy, 1946, vol. 1, No. 1, pp. 11–13). [In Czech].

Rhodesian Steel Scheme. (Iron and Steel, 1947, vol. 20, Nov. 20, pp. 553–556). An outline is given of a scheme for the local production of steel and ferro-chromium from the high-grade hematite ores known to exist south-west of Lusaka, in Rhodesia. The projected steelworks would be complementary to the erection of a hydro-electric plant at Kariba Gorge, on the Zambesi river, and economic utilization of part of the estimated annual output of 600,000 kW. from the hydro-electric station would entail annual outputs of at least 500,000 tons of steel and 50,000 tons of ferrochromium.—J. R.

Is It Possible to Transfer Part of the Metallurgical Industry from the Ruhr to France? J. Tille. (Hutnické Listy, 1947, vol. 2, No. 5, pp. 111–113). The French proposal to transfer some German steelworks from the Ruhr to Lorraine is discussed.—R. A. R.

The Economics of Electricity Supply in the Iron and Steel Producing and Processing Industries in the British Zone. G. Bremer. (Stahl und Eisen, 1947, vol. 66–67, Oct. 9, pp. 348–351).—R. A. R.

30 Years of Soviet Foundry Industry. J. Alexandrovský. (Hutnické Listy, 1947, vol. 2, No. 5, pp. 97–99). [In Czech]. The expansion of the Soviet foundry industry is reviewed.—R. A. R.

The Two-Year Plan in the Metallurgical Industry. E. Kozina. (Hutnické Listy, 1946, vol. 1, No. 2, pp. 38–40). [In Czech]. Some details of the two-year plan for the iron and steel industry of Czechoslovakia are given. It is intended to raise the production of pig iron and steel to 1·4 and 2·2 million metric tons respectively for 1948.—R. A. R.

How are We to Reconstruct Our Iron Industry? J. Jičinský. (Hutnické Listy, 1946, vol. 1, No. 3, pp. 49–57). [In Czech]. The world production of pig iron and steel since 1860 and present-day reconstruction plans in Russia, America, England, and Czechoslovakia are reviewed.—R. A. R.

The Present Position of the Enamelling Industry. L. Vielhaber. (Metalloberfläche, 1947, vol. 1, Jan., pp. 13–14).

Varnishes—A Progress Report. H. Weise. (Metall-oberfläche, 1947, vol. 1, Jan., pp. 15–18). The effect of the war on the manufacture and use of varnishes in Germany is reviewed.—R. A. R.

World Wide Wire Industry. (Wire and Wire Products, 1947, vol. 22, Oct., pp. 782–801, 849–852). Brief accounts are given of the histories and present positions of the wire industries in twelve of the principal producing countries. The notes are written by: Belgium—A. Boddaert and F. Reyntjens; Great Britain—R. S. Brown and G. W. Preston; Canada—H. D. Short and L. H. Doering; India—S. S. Gill; Spain—R. Quijano de la Colina; South Africa—J. W. Vander Laan and C. B. Welsh; Sweden—G. Svennson; Chile—J. L. Carrasco; Germany—various reporters; and Ireland—F. O'Neill.—C. O.

The Control of Coal. R. Regul. (Stahl und Eisen, 1947, vol. 66–67, Oct. 9, pp. 343–347). Earlier forms of coal control in Germany, its organization since 1945, and the allocation of the coal produced are discussed.—R. A. R.

The Metallurgist in Industry. Sir A. Smout. (Swansea Local Section of the Institute of Metals : Metal Industry, 1947, vol. 71, Nov. 28, pp. 439–441; Dec. 5, pp. 465–466 : Metallurgia, 1947, vol. 37, Nov., pp. 7–10). This is a discussion of the education and works training of metallurgists, and their function and scope in industry.—R. E.

The Metallurgist and Atomic Energy. R. E. Bacher. (Metal Progress, 1947, vol. 52, Nov., pp. 800–802). The contributions of metallurgists to the development of the atom bomb are briefly discussed and ways in which the stable and radio-active isotopes produced by nuclear reactions will be of use in metallurgical research are indicated.—C. O.

The Research Laboratory at the Klus Ironworks. W. Anderhub. (Von Roll Mitteilungen, 1947, vol. 6, Dec., pp. 85–91). A description is given of the new research laboratory at the Klus works of the L. von Roll A.G., Zürich, in which problems of physics, chemistry, and hydraulics are to be investigated.—R. A. R.

The Restoration of the Skoda Works. F. Marle. (Génie Civil, 1947, vol. 124, Dec. 1, p. 460). The progress made in the restoration of the Skoda Works is briefly described.—R. F. F.

Steelworks Maintenance. G. S. T. Martin. (West of Scotland Iron and Steel Institute, 1947, Preprint). The functions and organization of the maintenance department of an integrated iron and steel works are described.—R. A. R.

Metallurgical Progress and the Steam Engineer. L. Sanderson. (Steam Engineer, 1947, vol. 17, Nov., pp. 61–63). A short survey is made of recent metallurgical developments of interest to the steam engineer.—C. O.

The Design of Stiffeners and Flanges. S. Schwaigerer and R. Kobitzsch. (Technik, 1947, vol. 2, Oct., pp. 425–430).

Electronic Treatment of Feedwater. M. Déribéré. (Energie, 1947, vol. 31, Oct., pp. 242–246). The prevention of boiler scale by irradiation of feed-water is discussed. Two methods are described in detail: "Electronic Tubes," consisting of glass tubes containing mercury vapour and an inert gas, which, when excited, emit ultra-violet radiation, and the "Polyradia" installation which consists of a radio-active source and a magnetic β-ray accelerator.—R. F. F.

Investigation of German Methods of Rubber/Metal Bonding. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1530 : H.M. Stationery Office).

MISCELLANEOUS

The Redesign of a Direct Fired Air Heater. R. M. Rush, H. A. Pietsch, and D. H. Marlin. (Iron and Steel Engineer, 1947, vol. 24, Dec., pp. 105–108). Higher labour costs during the last years of the recent war necessitated the redesigning of a type of direct-fired air heater the performance of which had been quite satisfactory. The basic change decided upon was the use of metallic-arc-welded heat-resisting stainless steel in the combustion chamber, in place of the carbon steel hitherto employed. The savings achieved are enumerated, and they relieved a situation which threatened to result in the discontinuation of a previously profitable line of manufacture.—J. R.

Heat Transfer. A. Cholette. (Chemical Engineering Progress, 1948, vol. 44, Jan., pp. 81–87). The author studies the local and average coefficients of heat transfer at Reynolds numbers corresponding to the transition between streamline and turbulent flow.—R. A. R.

Heat Exchange at High Pressures. R. Legendre. (Chimie et Industrie, 1945, vol. 53, Jan., pp. 6–11). Factors influencing heat transfer at high pressures are studied.—R. F. F.

Pressure Drop through Packed Tubes. M. Leva and M. Grummer. (Chemical Engineering Progress, 1947, vol. 43, Oct., pp. 549–554; Nov., pp. 633–638; Dec., pp. 713–718). An equation is derived mathematically relating the pressure drop of a gas passing through a tube packed with smooth broken solids with the mass velocity, viscosity, and density of the gas and the packing particle diameter, shape factor ($0{\cdot}205\ A/V_s^2$) and voids in the bed. The effect of each variable was checked by experiments, and experimental results showed an agreement of $\pm 8\%$ with calculations. Further experiments were carried out to determine the effect of surface roughness. The roughness of clay or alundum increased the pressure drop by 50%; Aloxite granules, which are still rougher, more than doubled it. A graph is presented relating modified friction factors with modified Reynolds numbers. Finally, the estimation of voids is explained, and illustrated by sample calculations.—M. A. V.

Jernkontorets 200th Anniversary. H. Dahlerus. (Jernkontorets Annaler, 1947, vol. 131, No. 12, pp. 525–544). [In Swedish]. An account is given of the proceedings on September 5 and 6, 1947, in Stockholm, in connection with the official celebrations of the 200th Anniversary of the foundation of Jernkontoret.—R. A. R.

Activities of the Institute—1946. G. S. Rose. (Yearbook of the American Iron and Steel Institute, 1947, pp. 690–710). Brief reviews are made of the work of the various committees of the American Iron and Steel Institute during 1946.—C. O.

German Transformer Industry. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 682 : H.M. Stationery Office). This account of investigations into the German transformer industry includes references to the properties of the powder metals used for dust cores, the rolling of thin silicon-iron strip for laminations, and a process still in the laboratory stage for the manufacture of sheet metal direct from powder by rolling.—C. O.

The Training of Metallurgists for the Steel Industry. J. Chipman. (Yearbook of the American Iron and Steel Institute, 1947, pp. 85–93). *See* Journ. I. and S.I., 1947, vol. 157, Dec., p. 654.

Trends in Metallurgical Research. C. S. Smith. (Yearbook of the American Iron and Steel Institute, 1947, pp. 529–538). *See* Journ. I. and S.I., 1947, vol. 157, Nov., p. 479.

Small Rotary Laboratory Furnace. G. Pannetier. (Chimie et Industrie, 1947, vol. 57, Mar., pp. 250–251). A small laboratory furnace is described; ores may be treated in it with a given chemical reagent, the combustion gases being excluded from the furnace atmosphere.—R. F. F.

Electromagnetic Pumping of Molten Metals. M. Tama. (Iron Age, 1947, vol. 160, Dec. 4, pp. 68–70). A method of utilizing the movement in molten metals caused by electromagnetism, as in the induction furnace, for pumping the metals is indicated.—C. O.

Industrial Applications of Ultrasonics. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1504 : H.M. Stationery Office). Notes are made on a number of miscellaneous applications of ultrasonics on which research work was carried out during the war at Siemens-Schuckertwerke, Berlin. They include the flotation of minerals (not successful), the coagulation of smoke, fluxless soldering, and improving the microstructure of welded joints.—C. O.

Dielectric Heating—Bibliographic Study. Francine Appell. (Chimie et Industrie, 1947, vol. 58, Nov., pp. 449–456). Present knowledge on dielectric heating is reviewed.—R. F. F.

Bonding Rubber on Metals. J. G. Duval. (Chimie et Industrie, 1947, vol. 57, June, pp. 540–544). Methods and agents for bonding rubber to metals are surveyed, with special references to a new French product "Canite."—R. F. F.

Planning and Co-ordinating Steel Mill Lighting. W. H. Kahler. (Steel, 1947, vol. 121, Dec. 15, pp. 118–124). The selection and planning of the installation of the lighting for steel plants are discussed. The characteristics of ten suitable types of light source are summarized.—C. O.

Japanese Metallurgical Specifications, Iron and Steel, Special Steels, Special Non-Ferrous Alloys. (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./775 : H.M. Stationery Office).

BOOK NOTICES

AMERICAN FOUNDRYMEN'S ASSOCIATION. "*Analysis of Casting Defects.*" 8vo, pp. 133. Illustrated. Chicago, 1947. The Association. (Price $2.75).

This book has been prepared by the Analysis of Casting Defects Committee of the American Foundrymen's Association, and has been written to help foundrymen reduce and eliminate defective castings. Originally intended primarily for grey-iron founders, only four of the defects described (mass hardness, hard spots, inverse chill, and kish) are peculiar to grey iron, whilst the others occur in castings at some time in all foundries. Thirty-one basic castings defects are listed and described. Each defect is defined in terms which are simple yet sufficiently complete to make the defect recognizable. Illustrations show typical defects and supplement the definitions.—R. E.

ITERSON, F. K. TH. VAN. "*Plasticity in Engineering,*" 8vo, pp. ix + 174. Illustrated. London, 1947 : Blackie and Son, Ltd. (Price 8*s.* 6*d.*).

This book may be described as the swan song of the older theories of plastic flow of Hencky, Prandtl, and others. These theories allowed a certain freedom in the construction of slip-line systems of which the author has taken full advantage. New developments which have taken place in this country have led, by proper consideration of boundary conditions and the distribution of strain, to more exact solutions of many of the problems treated in this book.

It would be less than fair, however, to criticize the book from the standpoint of these new developments of which the author could not have been aware, but even judged by the older theories, it is difficult to agree with some of the solutions he gives, such as that for extrusion discussed on pp. 52–53, which does not appear to be in accord with practical experience. Others are so complicated that in the absence

of theoretical and experimental evidence to support them, we can only wonder whether some simpler solution might not have represented the facts just as well.

The book is also made the vehicle for a thesis that the stress required to initiate plastic flow is given by the Hencky-Mises criterion, but, as soon as flow starts, it falls to a value required by the Coulomb-Guest hypothesis. The author adduces the yield-point phenomenon in mild steel and the thixotropy of clay in support of this, but maintains a curious reticence about the behaviour of non-ferrous metals and steels which do not show the yield-point phenomenon.

All this is a pity since the author's intention of writing a simple textbook on plasticity is a laudable one, but it is on this intention that the book must be judged. One cannot help feeling that while the initiate may find some enlightenment, he will also find much bewilderment therein, while the inquiring reader, gazing in wonder at the author's often beautiful slip-line systems, will search in vain for their justification.

W. HESSENBERG

LUKENS STEEL COMPANY. "*Steel Plates and Their Fabrication.*" 8vo, pp. 408. Illustrated. Coatesville, Pa. : Lukens Steel Company. (Price $5.00).

This book is published as an aid to engineers, designers, and others who deal with steel plates and with structures of which they are a part. The first two sections deal briefly with the history of iron and steel making in the United States, and the events which lead up to the foundation of the Lukens Steel Company. Section 3 contains illustrated particulars of the Luken's 206-in. four-high plate mill. Section 4 outlines the manufacture of open-hearth steel and the rolling of plates, and Section 5 described the properties of carbon and low-alloy steels. The effect of plate width on fabrication costs is dealt with in Section 6, and the strength of flat plates and shells in Section 7. The next five Sections describe the forming, flanging and pressing, flame-cutting, welding, and riveting of plates. Section 13 describes the manufacture, properties and applications of clad steels, and Section 14 deals with fabricated assemblies. Pressure vessels and tanks are dealt with in Section 15. The final section consists of general engineering data, and includes mathematical tables, conversion tables, and other subjects of frequent reference.—R. E.

SPOWERS, W. H., Jun. "*Hot-Dip Galvanizing Practice.*" Second Edition. 8vo, pp. xi + 188. Illustrated. Cleveland, Ohio, 1947 : Penton Publishing Co. (Price 36*s.*).

The first edition of this work appeared in 1938 and much of the subject matter has been retained in the present edition, although it has been rearranged to conform more nearly to the sequence of operations. Some of the chapters have been abridged and one chapter deleted. Additions have been made to the chapters on "Control of Oxidation and Radiation in Galvanizing Kettles" and "Typical Modern Galvanizing Plant Construction and Procedure," and the bibliography has been brought up-to-date.—R. E.

STEPHANIDES T. "*The Microscope and the Practical Principles of Observation.*" 8vo, pp. 160. Illustrated. London, 1947 : Faber and Faber, Ltd. (Price 10*s.* 6*d.*).

This book is intended for medical students, research workers, and all who need to understand the proper handling of the microscope. Part I describes the construction of microscopes, and discusses the relative merits of the available types. Part II describes the technique of microscopical observation. Definitions of terms used in microscopy are appended.—R. E.

TIMKEN ROLLER BEARING COMPANY. "*Digest of Steels for High Temperature Service.*" Fifth Edition. La. 8vo, pp. 215. Illustrated. Canton, Ohio, 1946 : Timken Roller Bearing Company, Steel and Tube Division.

This digest, originally published in 1932 and revised in 1934, 1937, and 1939, present complete high-temperature data on twenty-two steels which have found general use in many different types of applications. Each of these steels are first considered individually in detail and then their more important physical properties are presented in tables and graphs for ready comparison to enable engineers to select the most suitable material for a particular job. A bibliography of the literature on the high-temperature properties of steels is appended.—R. E.

NEW PUBLICATIONS

AMERICAN FOUNDRYMEN'S ASSOCIATION. "*Analysis of Casting Defects.*" 8vo, pp. 133. Illustrated. Chicago, 1947 : The Association. (Price $2.75).

AMERICAN SOCIETY FOR TESTING MATERIALS. "*1947 Supplement to Book of A.S.T.M. Standards Including Tentatives.*" Part I-B, "*Non-Ferrous Metals.*" 8vo, pp. x + 317. (Price $4.00). Part II, "*Non-metallic Materials—Constructional,*" 8vo, pp. xvi + 462. Philadelphia : The Society. (Price $4.00).

AMERICAN WELDING SOCIETY. "*Standard Welding Symbols and Rules for Their Use.*" 8vo, pp. iv + 67. Illustrated. New York, 1947 : The Society. (Price 50 cents).

GORTER, C. J. "*Paramagnetic Relaxation.*" 8vo, pp. vii + 127. Illustrated. London, 1947 : Elseirer Publishing Co., Inc. (Price 12*s.*).

HARTOG, J. P. DEN. "*Mechanical Vibrations.*" Third Edition. 8vo, pp. xi + 478. New York, 1947 : McGraw-Hill Book Co., Inc. ; London : McGraw-Hill Publishing Co., Ltd. (Price 30*s.*).

INTERNATIONAL NICKEL COMPANY INC. "*Bibliography of Chromium Nickel Austenitic Stainless Steels. Physical and Mechanical Properties.*" Articles published between Jan. 1, 1935 and Dec. 31, 1945. 4to. New York : The Company.

ITERSON, F. K. TH. VAN. "*Plasticity in Engineering.*" 8vo, pp. ix + 174. Illustrated. London, 1947 : Blackie and Son, Ltd. (Price 8*s.* 6*d.*).

LAUER, H., R. LESNICK and L. E. MATSON. "*Servo-mechanism Fundamentals.*" 8vo, pp. xi + 277. New York, 1947 : McGraw Hill Book Co., Inc. ; London : McGraw-Hill Publishing Co., Ltd. (Price 17*s.* 6*d.*).

MORITZ, H. "*Spektrochemische Betriebsanalyse.*" (Die Chemische Analyse 43 Bd.). 8vo, pp. xi + 170. Illustrated. Stuttgart, 1946 : Ferdinand Enke Verlag.

SCHWARZKOPF, P. "*Powder Metallurgy. Its Physics and Production.*" 8vo, pp. xii + 379. New York, 1947 : The Macmillian Co. (Price $8.00).

SIMONS, E. N. "*Steel Files. Their Manufacture and Application.*" 8vo, pp. ix + 136. Illustrated. London, 1947 : Sir Isaac Pitman and Sons, Ltd. (Price 15*s.*).

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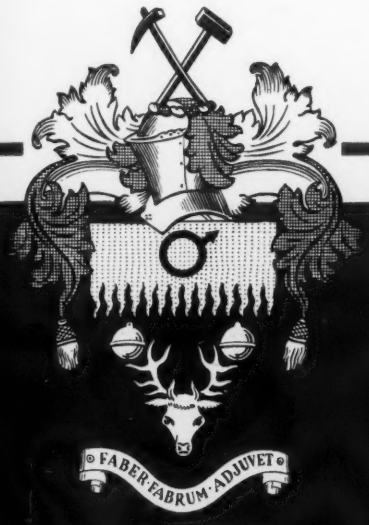

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The Maintenance of Electrical Machinery in Iron and Steel Works..*by G. S. Martin and M. Y. Harvey*

News and Abstracts

A full list of Contents is given on the Title Page (see page 33, Advertisement Section)

DAVY-UNITED ROLLS

Yardstick

OF ROLLING EFFICIENCY

EXPERIENCE—and SUCCESS in the manufacture of all kinds of Rolls can be claimed by this Company whose old-established Foundry at Billingham has been producing Rolls for 40 years. Constant improvement in manufacturing methods has been possible by intensive research not only in our own Foundry but also in collaboration with the Roll user.

Chilled Grain and Steel Rolls.

For Steel, Iron, Copper, Brass, Aluminium, Zinc, etc.

CLEVELAND SPECIAL Grain Rolls.

ALLOY and DUPLEX Chilled Rolls.

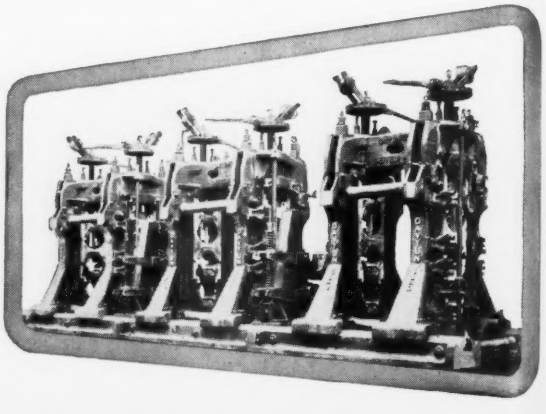
CARBON and ALLOY Cast Steel Rolls.

SPECIAL WORK ROLLS for 4-High Mills.

X.L. STEEL BASE Special Rolls.

THE DAVY-UNITED GROUP

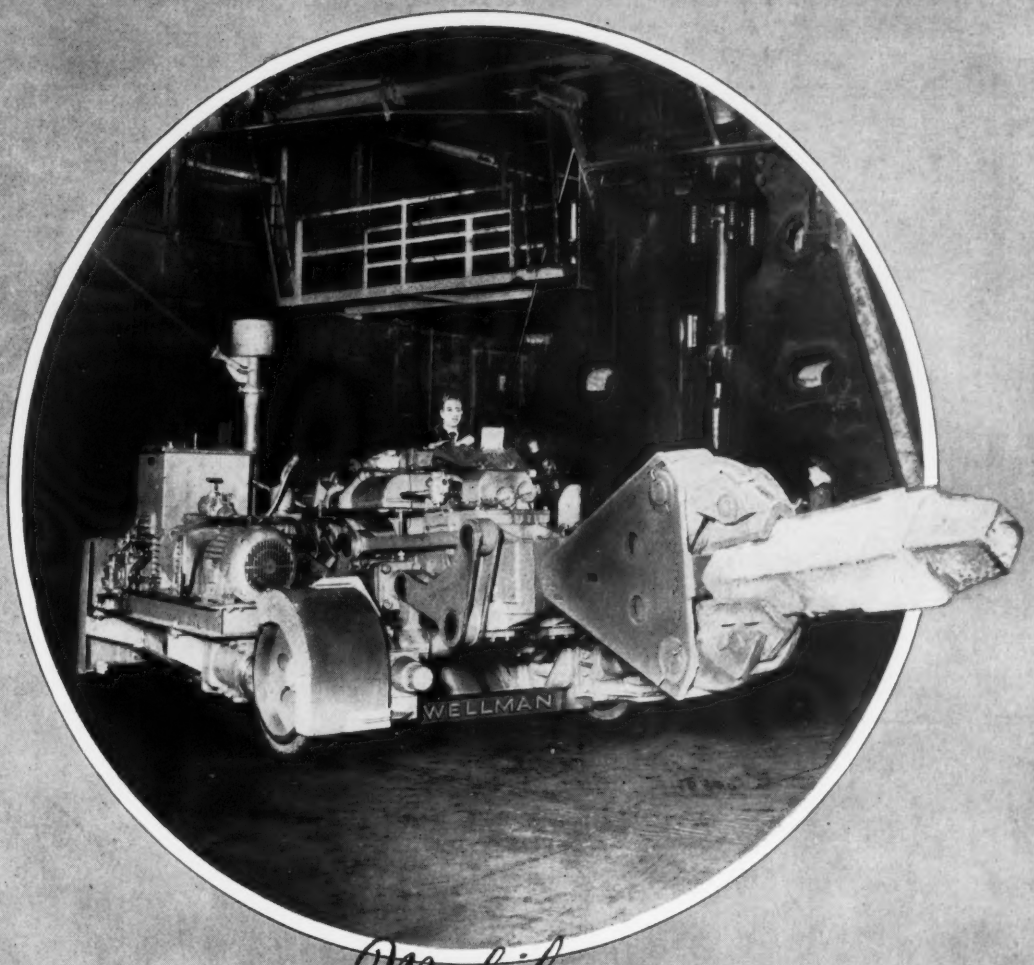
Our Roll experts will be pleased to give Roll users their experience in the practical application of the various types of DAVY-UNITED ROLLS.
Here three roughing and finishing stands of a 28" 3-High Plate, Blooming, Rail and Structural Mill await the fitting of their Davy-United Rolls.



DAVY AND UNITED ROLL FOUNDRY LIMITED, BILLINGHAM

PROPRIETOR: DAVY AND UNITED ENGINEERING COMPANY, LIMITED, SHEFFIELD

WELLMAN



Mobile
Forging Manipulators

Capable of handling ingots up to 20″ square and 3 tons in weight this Wellman Mobile Forging Manipulator operates between the furnace and forging press at Messrs. Brown, Bayley's Steelworks Ltd., Sheffield. The Manipulator is equipped with special mechanism so that the workpiece can be maintained in any desired position while it is being forged.

Wellman Mobile Machines also include Box Chargers for Electric and Open Hearth Steel Furnaces — Tyre Cheese Handlers — Ingot Handling and Charging Machines — in various capacities to meet particular requirements.

THE WELLMAN SMITH OWEN ENGINEERING CORPORATION LIMITED
PARNELL HOUSE, WILTON ROAD, LONDON, S.W.1 WORKS: DARLASTON, SOUTH STAFFS.

THE STEEL COMPANY OF WALES LIMITED

REGISTERED OFFICE
ABBEY WORKS
PORT TALBOT

INCORPORATING

STEEL DIVISION

MARGAM & PORT TALBOT WORKS
FORMERLY OF
GUEST KEEN BALDWINS IRON & STEEL CO., LTD.

TINPLATE DIVISION

THE TINPLATE WORKS
FORMERLY OF
RICHARD THOMAS & BALDWINS LTD.
KNOWN AS

BURRY	MARDY
R. T. MILLS	GROVESEND
SOUTH WALES	GORSEINON
MORFA	HENDY
DYFFRYN	KINGS DOCK
GLANRHYD	MELINGRIFFITH
PONTARDAWE	LYDNEY

THE TINPLATE WORKS
FORMERLY OF
LLANELLY ASSOCIATED TINPLATE COMPANIES LTD.
KNOWN AS

OLD CASTLE	TEILO
WESTERN	ASHBURNHAM

THE STEEL COMPANY OF WALES (LYSAGHT WORKS) LTD.
COMPRISING
ORB IRON WORKS, NEWPORT
FORMERLY OF
JOHN LYSAGHT, LTD.

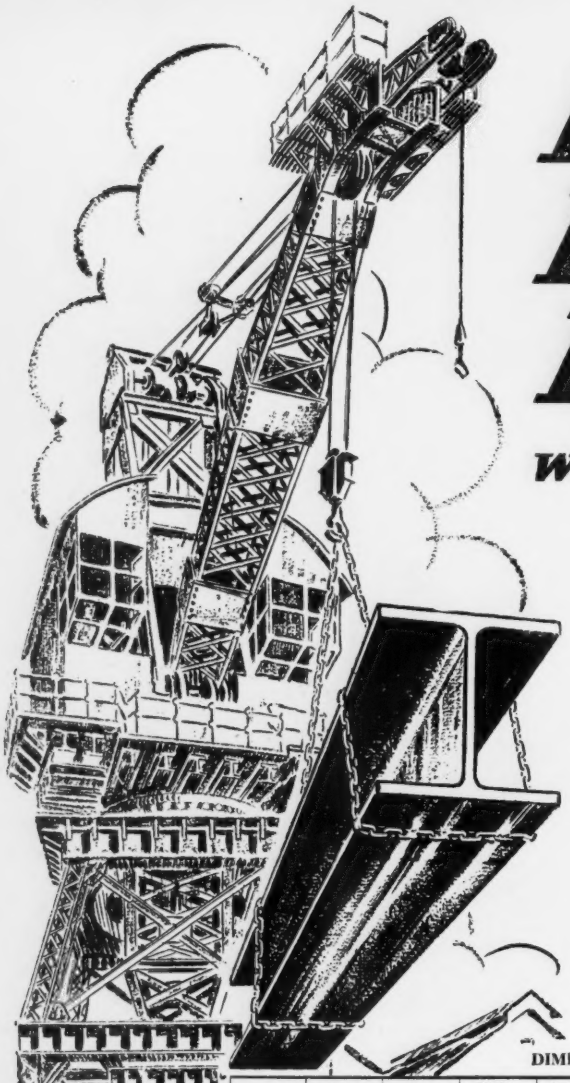
High frequency induction heating is the answer....

High frequency induction heating is the answer to many heat treatment problems. Correctly applied, it provides increased production at reduced cost, particularly of mass produced parts requiring accurate control. The Philips Electronic-heating Advisory Service invites your enquiries. Write to Dept. E, at the address below.

PHILIPS

PHILIPS ELECTRICAL LTD.

ELECTRONIC HEATING DEPT., ABOYNE WORKS, ABOYNE RD., LONDON, S.W.17.



CARGO FLEET BRITISH ROLLED

BROAD FLANGE BEAMS

with parallel flanges

These beams hitherto only produced on the Continent and in the United States of America are now being rolled in substantial quantities at the works of Cargo Fleet Iron Co. Ltd. They offer many advantages to the steelwork designer and where suitably employed, result in considerable savings in time, money, and weight. All heavier sections of rolled steel joists from 6" x 5" upwards can be replaced by Broad Flange Beams which are particularly suited for Stanchions, Stanchions for Crane Runways, Main Girders, Girders to support brickwork, etc. Compared with riveted and compounded sections, risk of corrosion is considerably reduced and maintenance costs for painting are lower. Our advisory staff is at all times at your service.

ORDERS CAN NOW BE ACCEPTED FOR THE FOLLOWING SECTIONS:

6 x 6, 8 x 8, 10 x 10, 12 x 12, 14 x 12, 16 x 12, 18 x 12, 20 x 12.

Full technical details and advice on request.

CARGO FLEET STEEL — STRENGTH & SECURITY

DIMENSIONS AND PROPERTIES

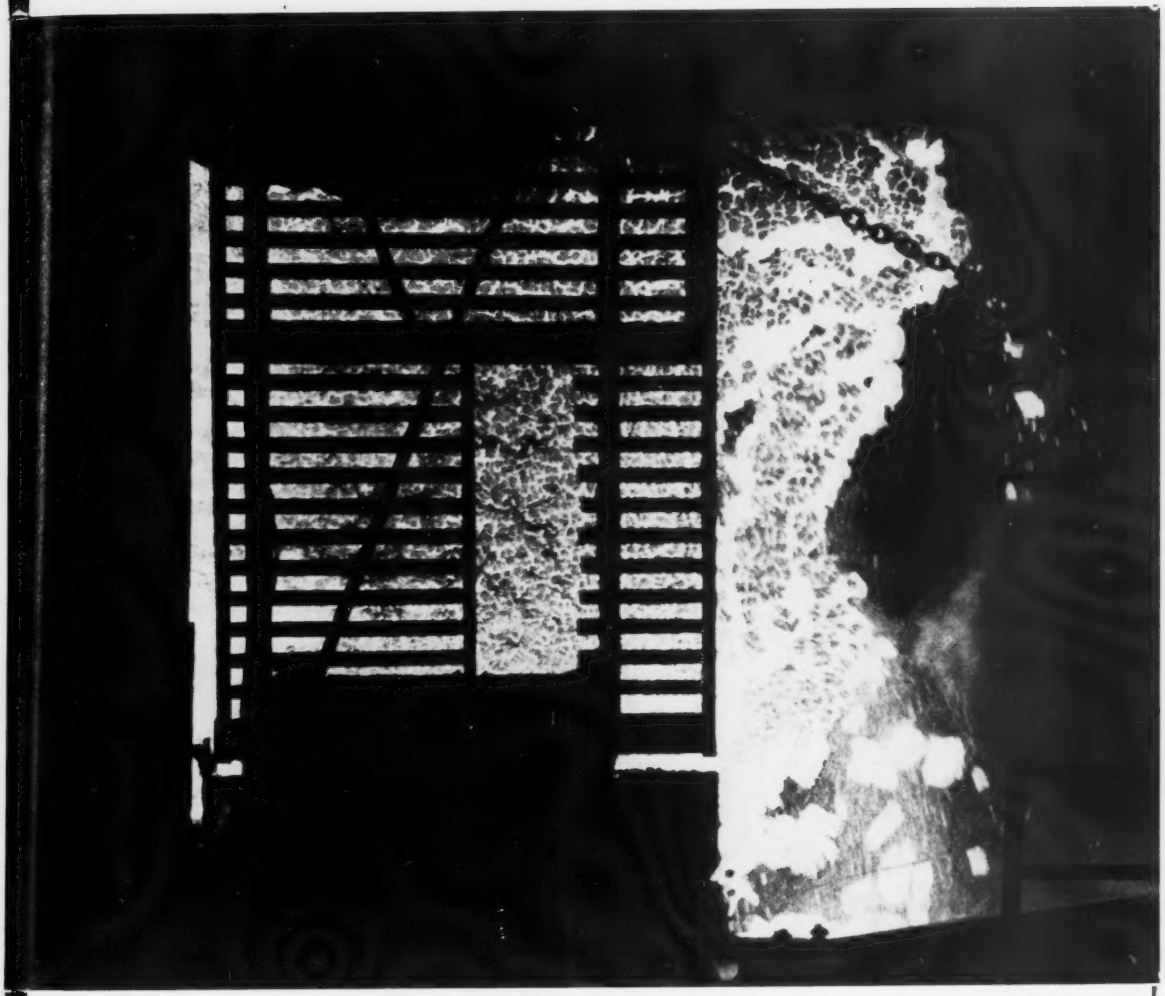
Size d x b inches	Wt./Lbs. per Ft. =W	Area in sq. ins.	Web Ratio Depth / Web	Thickness		Moment of Inertia - I		Modulus of Section - Z		Radius of Gyration - R.G.		Zxx x 1000
				Web	Flange	X - X	Y - Y	X - X	Y - Y	X - X	Y - Y	Wt. (lbs.) x Depth (ins.)
6 x 6	25	7·353	19·35	·31	·46	47·24	16·76	15·75	5·59	2·53	1·51	105
8 x 8	45	13·23	20·5	·39	·64	152·76	55·02	38·19	13·75	3·39	2·04	106
10 x 10	62·63	18·42	23·25	·43	·72	338·97	119·94	67·79	23·98	4·29	2·54	108·2
12 x 12	82·55	24·278	25·53	·47	·79	652	228	108·6	38·0	5·18	3·07	109·6
14 x 12	100	29·412	25·45	·55	·92	1048·44	265·25	149·78	44·21	5·97	3·00	107
16 x 12	110	32·352	29·1	·55	1·0	1504·6	288·3	188·1	48·05	6·82	2·98	106·8
18 x 12	122	35·882	30·5	·59	1·08	2094·5	311·4	232·7	51·90	7·64	2·946	106
20 x 12	135	39·706	31·746	·63	1·16	2808	334·65	280·8	55·78	8·41	2·903	104

CARGO FLEET IRON CO. LTD.

Steel Manufacturers and Constructional Engineers

MIDDLESBROUGH, STOCKTON ON TEES and LONDON.

THE 8,500TH PUSH . . .



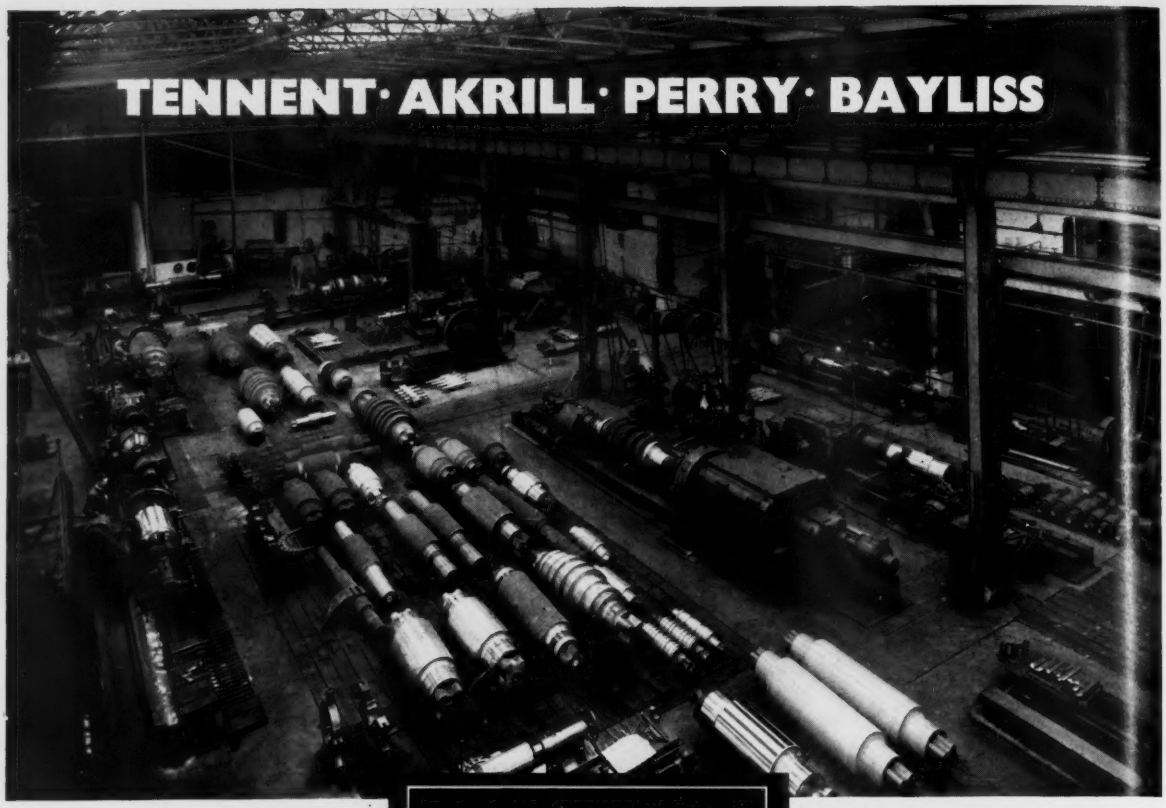
W-D

Each oven in the battery of 47 W-D Becker Coke Ovens at the Normanby Park Works of John Lysaght's Scunthorpe Works Limited has now been pushed over 8,500 times.

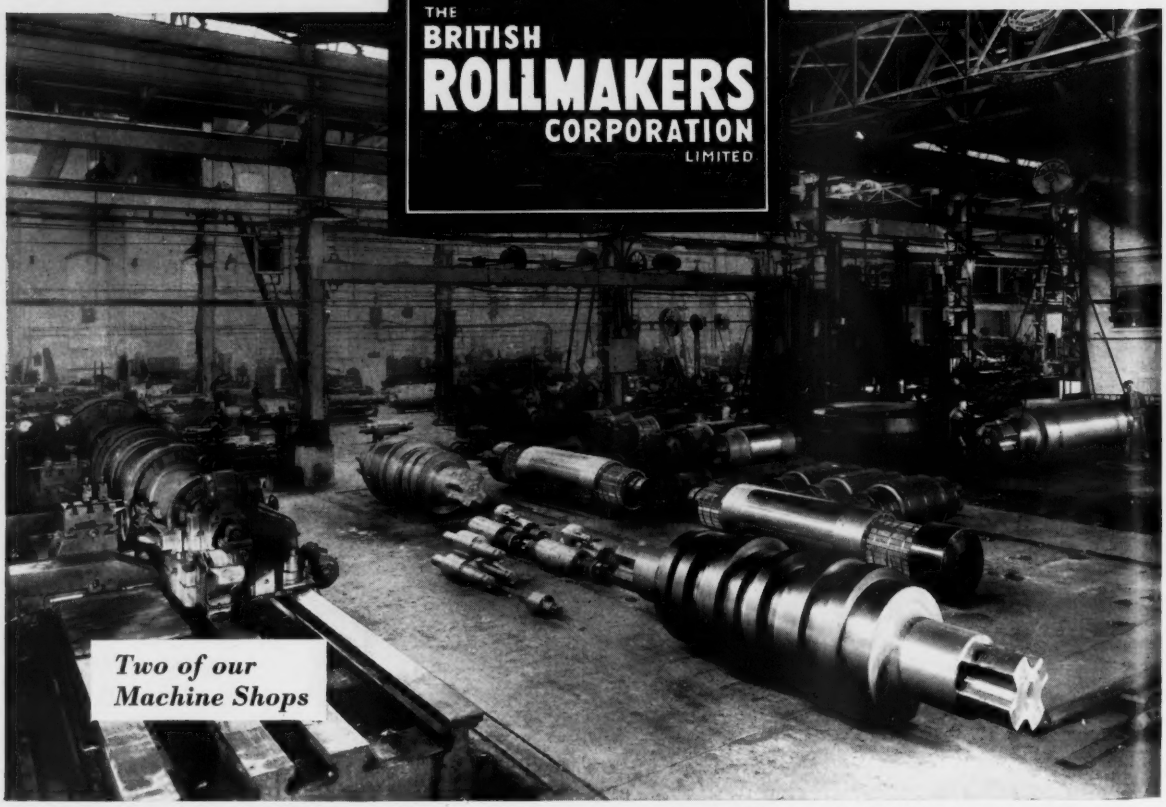
120,000 TONS PER OVEN and still in excellent working condition

THE WOODALL-DUCKHAM VERTICAL RETORT & OVEN CONSTRUCTION CO. (1920) LTD.
EBURY AND ALLINGTON HOUSES, 136-150 VICTORIA STREET, LONDON, S.W.1
TELEPHONE: VICtoria 7001-5 *Members of the Society of British Gas Industries* TELEGRAMS: RETORTICAL (SOWEST) LONDON

TAS/W-D.19



THE BRITISH ROLLMAKERS CORPORATION LIMITED



R. B. TENNENT LTD., WHIFFLET FOUNDRY, COATBRIDGE, SCOTLAND. TELEPHONE: COATBRIDGE 425
C. AKRILL LTD., GOLD'S GREEN FOUNDRY, WEST BROMWICH. TELEPHONE: WEDNESBURY 0225
THOMAS PERRY LTD., HIGHFIELDS WORKS, BILSTON. TELEPHONE: BILSTON 41224
BAYLISS ROLLS LTD., VICTORIA WORKS, WOLVERHAMPTON. TELEPHONE: WOLVERHAMPTON 20441

M-W.49

'SPIRACTOR' SAVES COAL

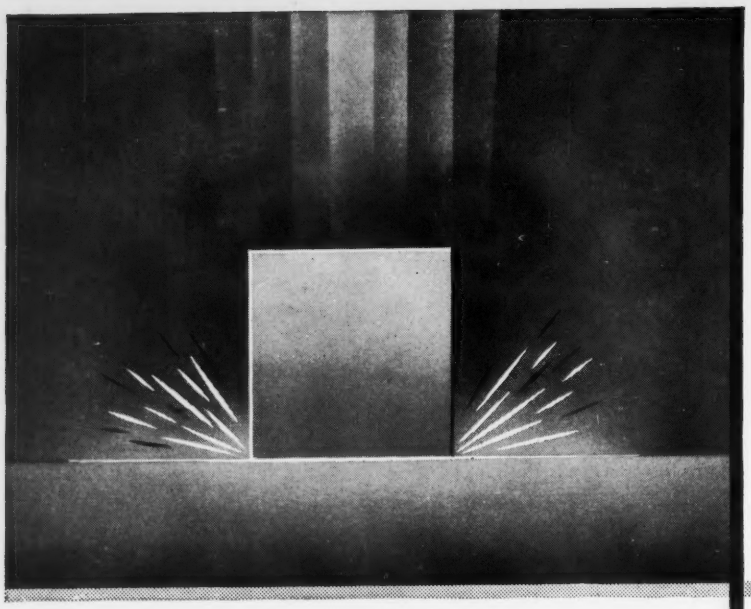
This latest method of softening Boiler Feed Water plays an important part in effecting the utmost economy in fuel demanded by present conditions.

The 'Spiractor' is a new type of cold-lime water softening process embodying a revolutionary principle. The process effects the removal of calcium temporary hardness in less than *five minutes* as against the normal time of 3-4 hours — substitutes easily removed granules for voluminous wet sludge — is small in size — readily adjustable to changes in water — eliminates pumping and has no moving parts. The removal of residual permanent hardness is carried out by a Permutit Fully Automatic Base Exchange Softener.

For full details of the 'Spiractor' Process and details of our Water Softening Equipment send your enquiries to the address below.

The 'Spiractor' Plant is manufactured by . . .

THE PERMUTIT CO. LTD., Dept. W.C., Permutit House, Gunnersbury Ave., London, W.4. CHIswick 6431



For things that go bump ...

Parts that get knocked about pose a very nice problem in steel selection. In too many types, when the steel is hard enough it isn't tough.

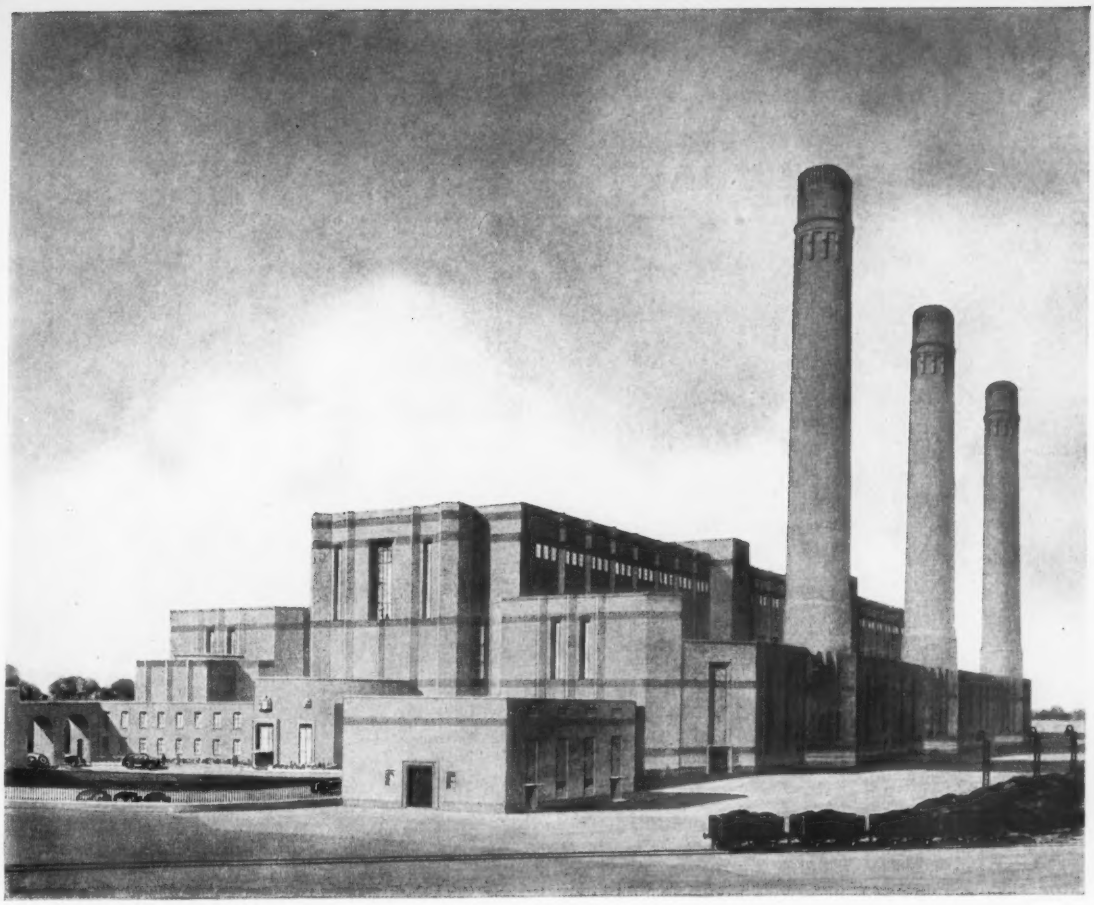
Molybdenum steels are tough when they are hard. That accounts for their use in so many applications, such as chisels, power shovel teeth and pile drivers where the combination is a primary requisite.

Your supplier can tell you about these steels, and we can also furnish data concerning them.

CLIMAX MOLYBDENUM COMPANY OF EUROPE LIMITED
2 & 3 CROSBY SQUARE, LONDON, E.C.3

MOLY

C7



Architect: Robert Atkinson, F.R.I.B.A. *Consulting Civil Engineers: C. S. Allott & Son*

Chief Engineer-General Manager & Consulting Engineer: F. N. Rendell-Baker, M.I.E.E.

CROYDON 'B' STATION

One of Britain's latest power stations which is now in course of construction at Croydon. The complete steam generating plant, consisting of the most modern design high pressure water tube boilers, together with the ash and dust handling plants, are by Simon-Carves.

SIMON-CARVES LIMITED

CHEADLE HEATH · STOCKPORT

EXHIBIT A

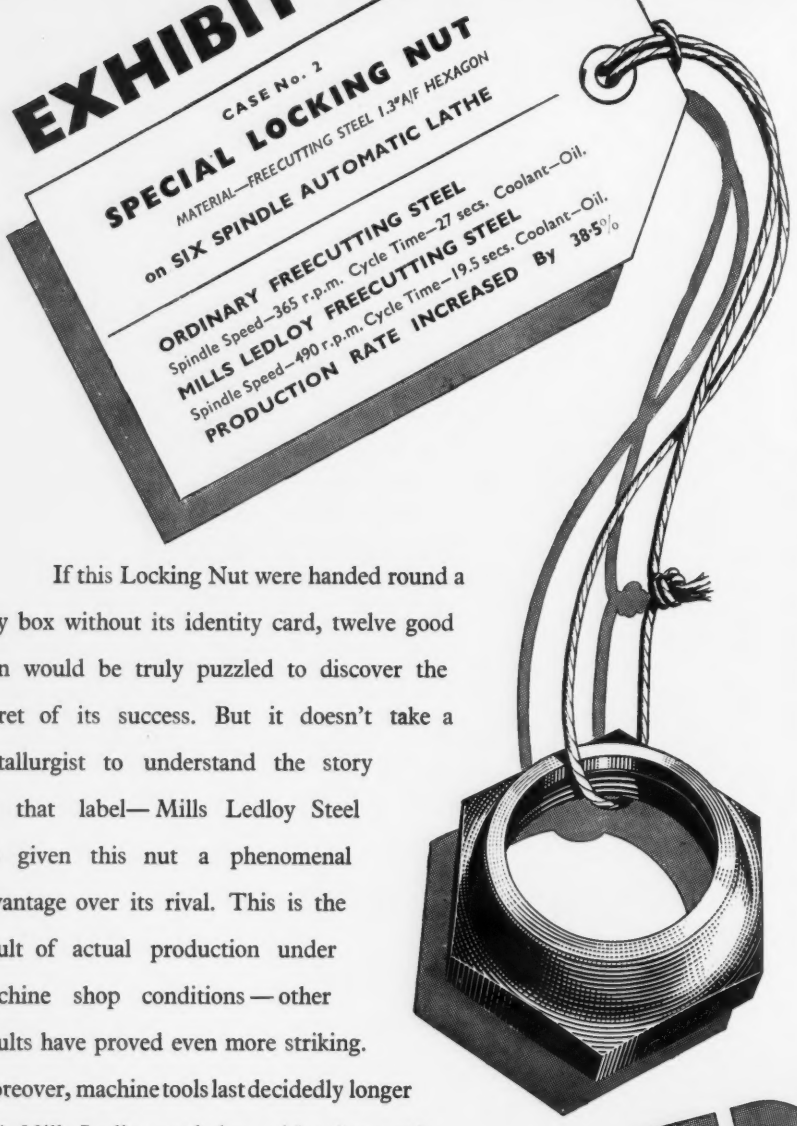
CASE No. 2

SPECIAL LOCKING NUT

MATERIAL—FREECUTTING STEEL 1.3"A/F HEXAGON

on SIX SPINDLE AUTOMATIC LATHE

ORDINARY FREECUTTING STEEL
Spindle Speed—365 r.p.m. Cycle Time—27 secs. Coolant—Oil.
MILLS LEDLOY FREECUTTING STEEL
Spindle Speed—490 r.p.m. Cycle Time—19.5 secs. Coolant—Oil.
PRODUCTION RATE INCREASED By 38·5%



If this Locking Nut were handed round a jury box without its identity card, twelve good men would be truly puzzled to discover the secret of its success. But it doesn't take a metallurgist to understand the story on that label— Mills Ledloy Steel has given this nut a phenomenal advantage over its rival. This is the result of actual production under machine shop conditions — other results have proved even more striking. Moreover, machine tools last decidedly longer with Mills Ledloy steel than with other steels.

STOCKHOLDING AGENTS

LONDON
Brown Brothers Ltd.
Buck & Hickman Ltd.
Farmer, Stedall & Co.
Mosers Ltd.
W. & C. Tipple Ltd.

MANCHESTER
Alfred Simpson Ltd.

BELFAST
Kennedy & Morrison Ltd.

BIRMINGHAM
Chas. Wade & Co. Ltd.

BRISTOL
Godwin, Warren & Co. Ltd.

NORTHAMPTON
A. H. Allen & Co. Ltd.

GLASGOW
John & Chas. Murray

KEIGHLEY
John W. Laycock Ltd.

NEWCASTLE-ON-TYNE
Guest, Keen & Nettlefolds Ltd.

NOTTINGHAM
Associated Engineering & Electrical Supplies Co. Ltd.

MILLS LEDLOY

EXORS OF JAMES MILLS LTD.

BREDBURY STEEL WORKS.

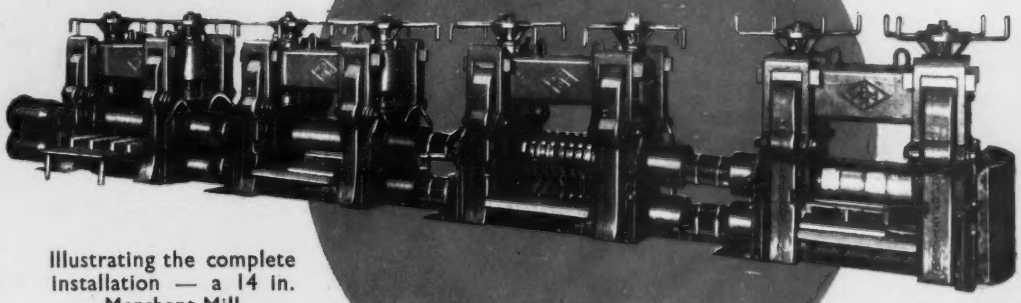
WOODLEY. Nr. STOCKPORT

LEDLOY is the name given to steels into which a small percentage of lead has been introduced by a special process. All steels (carbon and alloy) can be so treated during their manufacture.

ROBERTSON

HOT ROLLING MILLS

Part of a four-stand Hot Rolling Mill recently designed and constructed by W. H. A. Robertson of Bedford.



Illustrating the complete installation — a 14 in. Merchant Mill.

W. H. A. ROBERTSON & CO. LTD., BEDFORD

GRAMS: Whitehead, Newport

WHITEHEAD
IRON & STEEL
COMPANY
LIMITED
NEWPORT
MON.

PHONE: 3161 Newport

Hot Rolled Steel

HOOPS
and
STRIP
BARS:
Round
Square
Flat

FERRO-
CONCRETE
BARS
bent
to
specification

Bright Drawn Steel Bars

for all purposes

SPECIALITY:—
WHISCO
(REG'D)
BRAND.

Cold Rolled Steel Strip

in all qualities including
Special
Deep
Stamping
Steel
in
cut lengths
or coils

Speciality:
VERY
HEAVY
CONTINUOUS
LENGTH
COILS

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BRIGHTSIDE

ANOTHER BRIGHTSIDE ROLLING MILL AT WORK

This mill deals with a wide range of billet sizes, with a very high output capacity derived from the latest technique in mechanical manipulation. It is a two-stand 16 in. three-high roughing mill driven by a 750 H.P. D.C. variable speed motor and high-speed flywheel set.

THE BRIGHTSIDE FOUNDRY & ENGINEERING CO. LTD. SHEFFIELD
P.O.Box 118

BS20

one more from our records

We have recently installed the complete furnace equipment in a new plant for the manufacture of locomotive springs. This includes the Nebbing and Slotting Furnaces, Heating Furnaces for bending, and the final Treatment Furnaces. The photograph shows a coke-oven gas-fired Tempering Furnace, which is of the belt conveyor type, arranged for full recirculation and fitted with automatic temperature control.

WINCOTT FURNACES

G.P. WINCOTT LIMITED SHEFFIELD, ENGLAND

Telegrams: WINCOTT, SHEFFIELD. *Telephone: 20211/2*

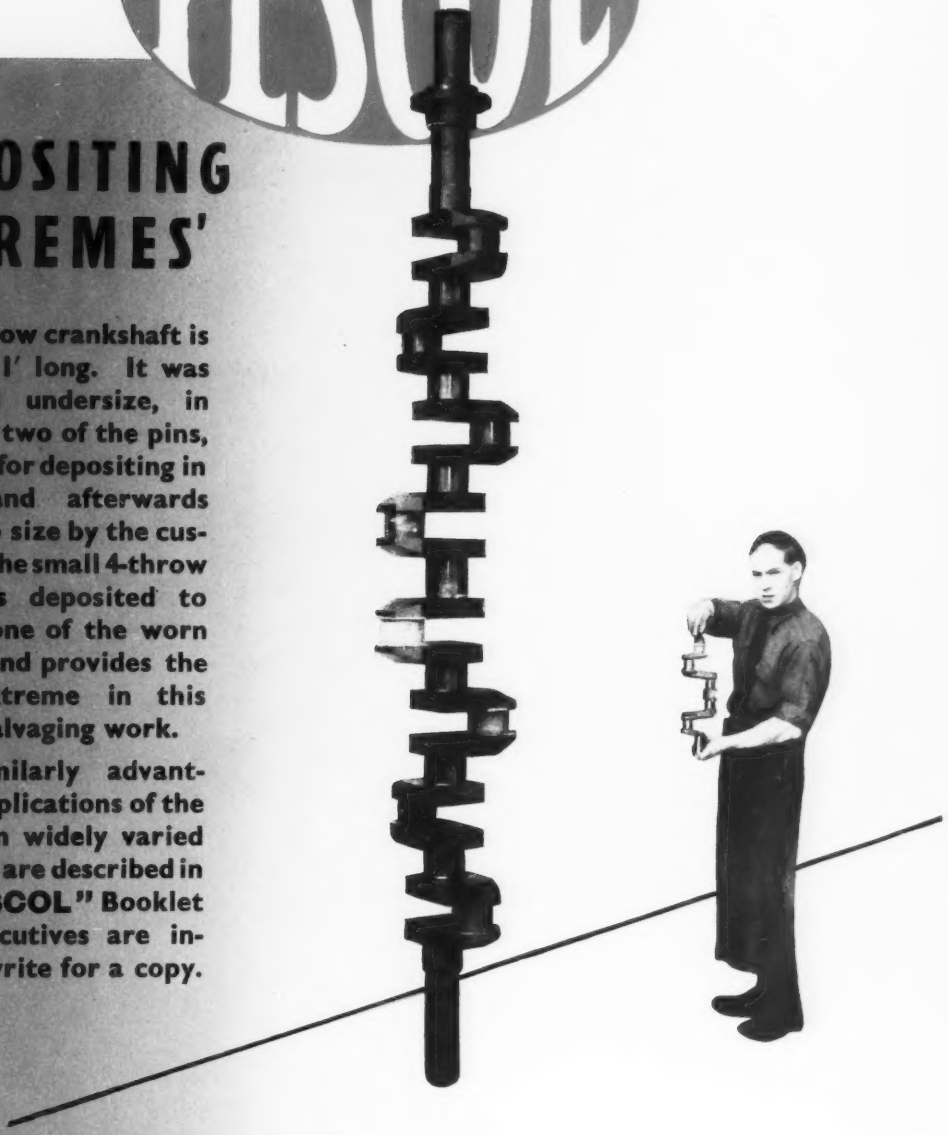
SB/W/4

FESCOL

'DEPOSITING EXTREMES'

The 8-throw crankshaft is approx. 11' long. It was machined undersize, in error, on two of the pins, sent to us for depositing in Nickel and afterwards ground to size by the customer. The small 4-throw shaft was deposited to build up one of the worn journals and provides the other extreme in this class of salvaging work.

Many similarly advantageous applications of the process in widely varied industries are described in the "FESCOL" Booklet I.S.4. Executives are invited to write for a copy.



FESCOL LIMITED

ORIGINATORS OF HEAVY DEPOSITION

REGISTERED FESCOL TRADE MARK

SOLE LICENSEES FOR FRANCE: SOCIETE FESCOL, 140, RUE DU CHATEAU, BOULOGNE-SUR-SEINE.
SOLE LICENSEES FOR AUSTRALASIA: DE HAVILLAND AIRCRAFT, PTY. LTD., MILPERRA ROAD, BANKSTOWN, N.S.W.

Scottish Address : PORT GLASGOW

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A NEW DEVELOPMENT IN STEEL PYROMETRY

TINSLEY *introduces*

ROOF TEMPERATURE MEASUREMENT AND CONTROL

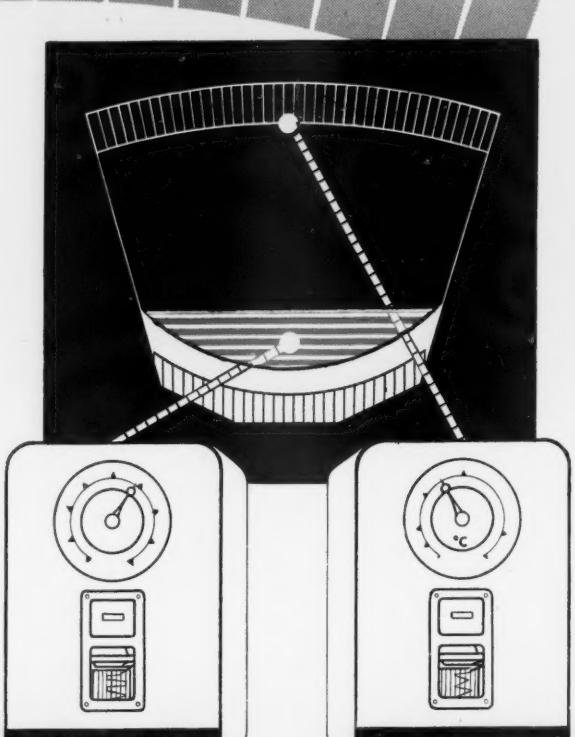
ONCE again Tinsley makes a new and vital contribution in the field of Steel Pyrometry . . . . ROOF TEMPERATURE MEASUREMENT. This new development, used in conjunction with their already widely known system in Liquid Steel Temperature Measurement, permits a new degree of efficiency and precision in Open Hearth Furnace operation. Furnaces equipped with the Tinsley Roof Temperature Measurement system can be safely operated at higher constant temperatures—*giving :*

INCREASED OUTPUT OF STEEL.
LONGER ROOF LIFE.
REDUCED REFRACTORY CONSUMPTION.

Salient features of the Tinsley system are :—

- NPL Calibration.
- Negligible Servicing.
- Complete Stability.
- No Absorption Errors.

Twin photo electric radiation heads with automatic switching dependability.



TINSLEY

(INDUSTRIAL INSTRUMENTS) LTD

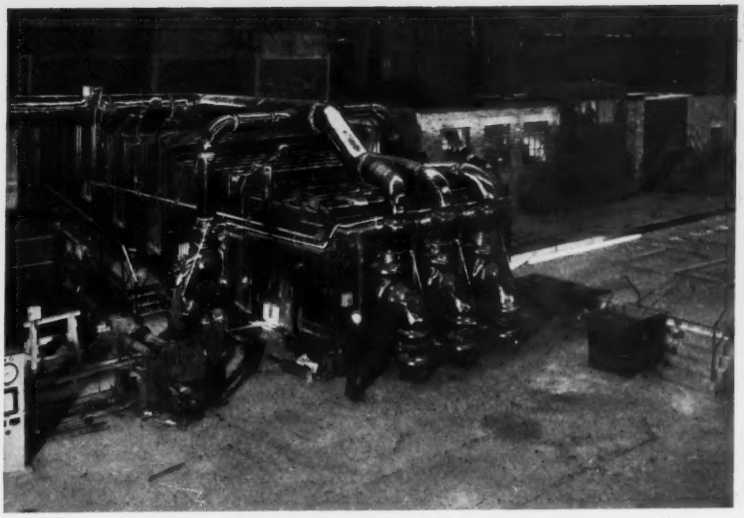
WERNDEE HALL LONDON S. E. 25.

HEATING FURNACES

OF ALL TYPES

ANNEALING FURNACES
REHEATING FURNACES
FORGE FURNACES
WIRE & STRIP FURNACES

CONSULTATIONS AND REPORTS



Continuous Billet Reheating Furnace with Typhoon Burners.

Other Specialities :

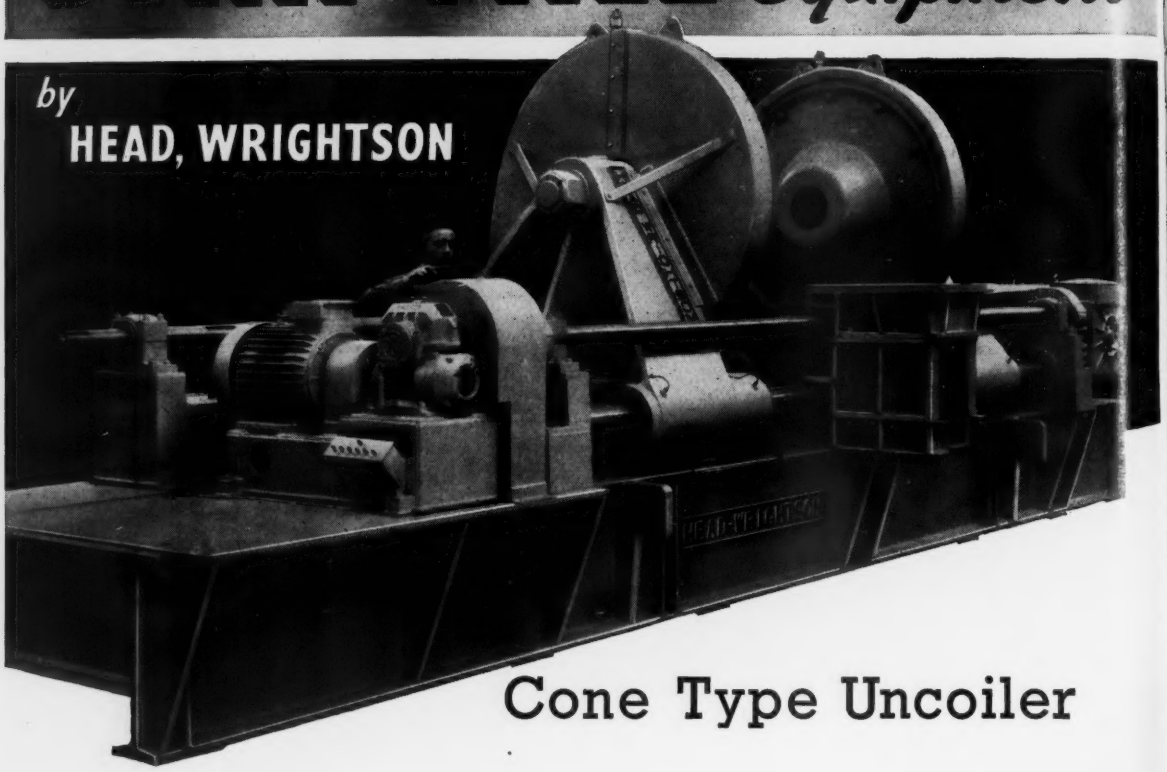
MORGAN GAS MACHINES
SOAKING PITS (ISLEY CONTROLLED)
HOT METAL MIXER CARS
MORGAN CONTINUOUS ROLLING MILLS
TYPHOON ROTARY FLAME GAS BURNERS
MILL FURNACES
"ARCA" GAS PRESSURE REGULATORS
"PHŒNIX" AUTOMATIC LIFTING DOGS

The

INTERNATIONAL CONSTRUCTION CO.
LIMITED
SUCCESSORS TO JULIAN KENNEDY-SAHLIN & CO. LTD.
56 KINGSWAY, LONDON. W.C.2
Phone : Holborn 1871-2
Grams : Sahlin, Westcent 2, London

STRIP MILL *Equipment*

by HEAD, WRIGHTSON



Cone Type Uncoiler

for

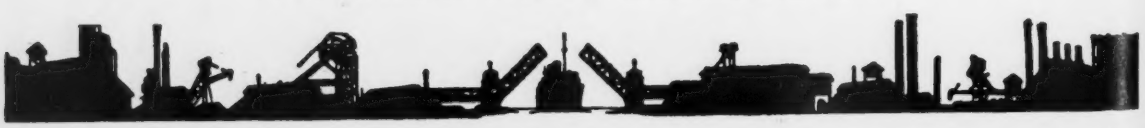
Pay-Off Reels
Tension Reels
Slitters
Edge Trimmers
Pinch Rolls
Roll Type Coilers
Oiling Machines
Pickling Plant
Tinning Plant
Galvanizing Plant
Shears
Scrap Ballers
etc., etc.

The unit illustrated is a Cone Type Uncoiler designed and built by Head Wrightson as part of a line recently installed for uncoiling and levelling cold rolled steel strip up to 80″ wide and in coils of 10 tons weight.

Consult

THE HEAD, WRIGHTSON MACHINE Co. LTD.

COMMERCIAL STREET, MIDDLESBROUGH



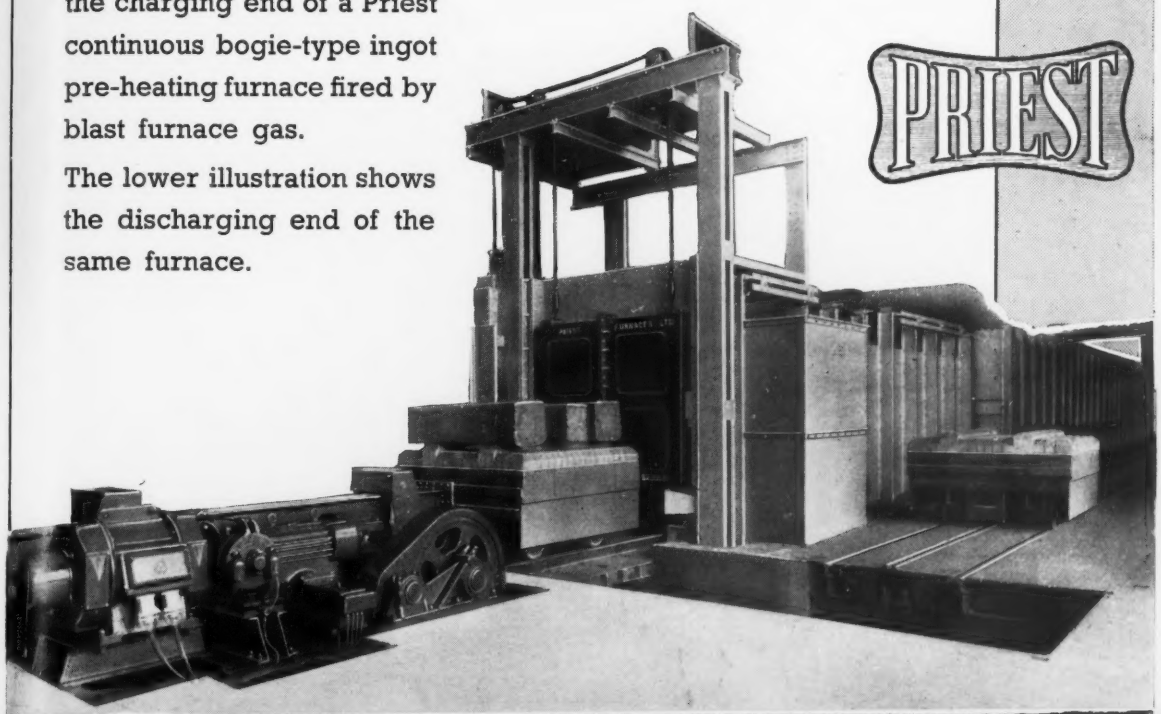
140-L

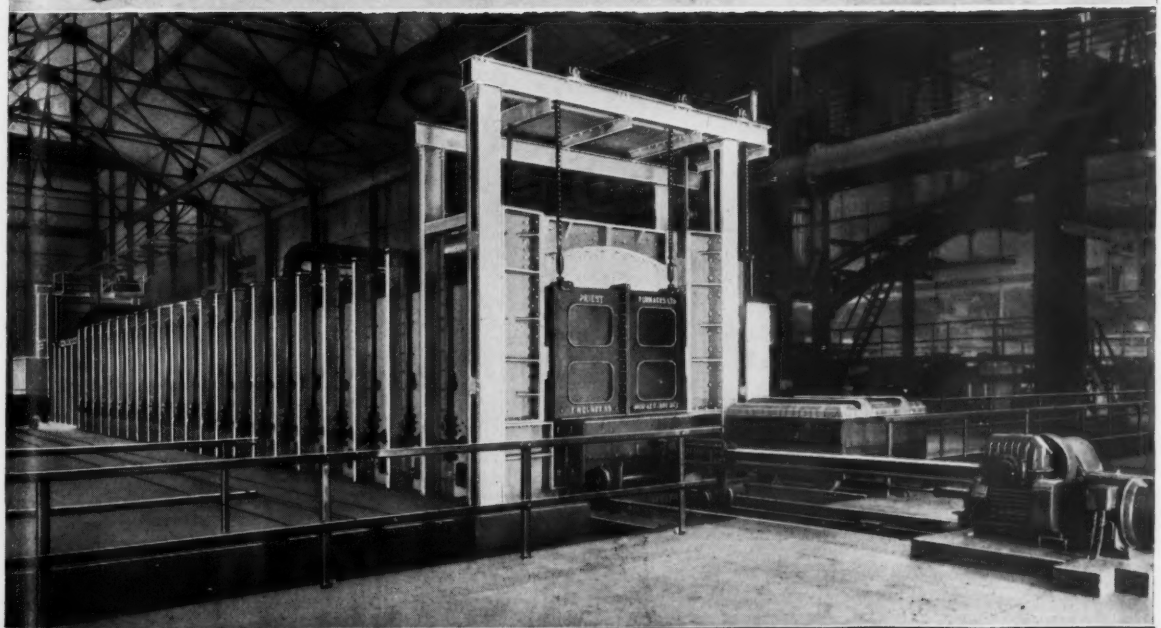
PRIEST FURNACES

The upper illustration shows the charging end of a Priest continuous bogie-type ingot pre-heating furnace fired by blast furnace gas.

The lower illustration shows the discharging end of the same furnace.

PRIEST





PRIEST FURNACES LIMITED · LONGLANDS · MIDDLESBROUGH

also at TELEGRAPH BUILDINGS · HIGH ST · SHEFFIELD

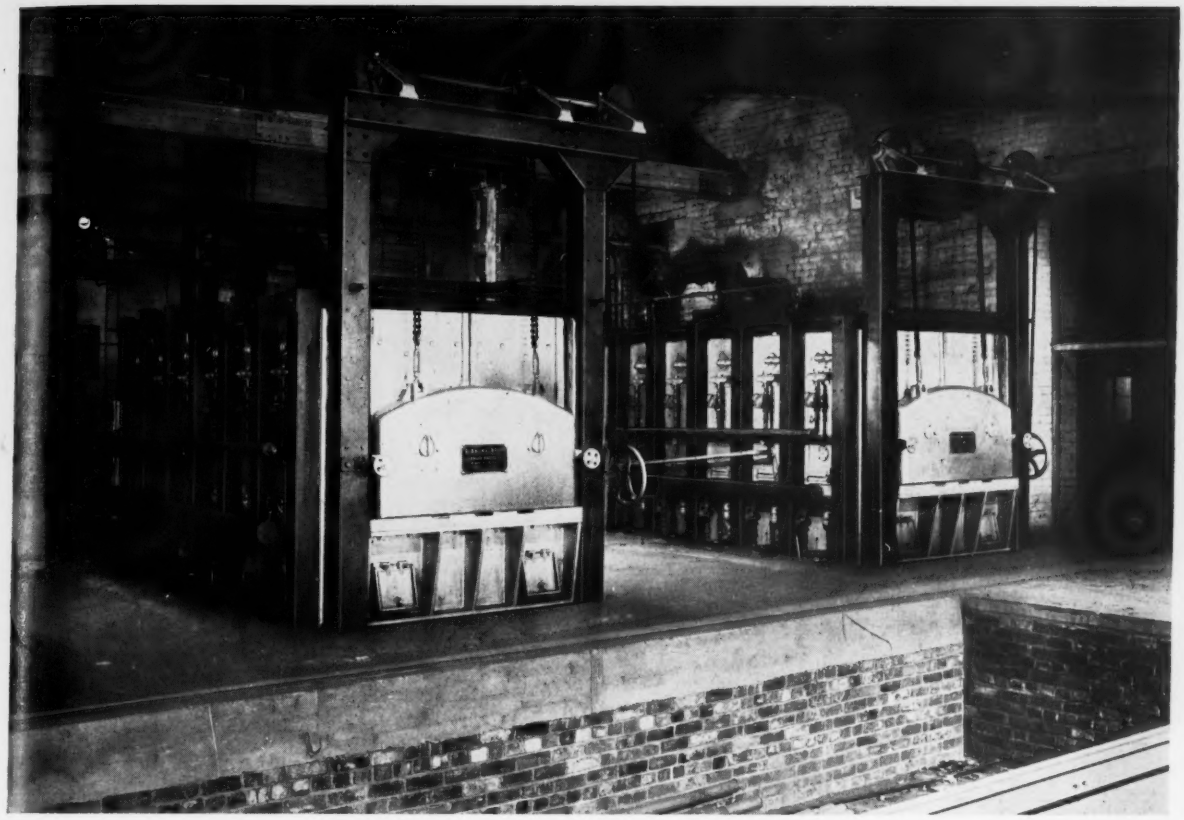
MAKERS OF STEEL CASTINGS FOR THE RAILWAY SYSTEMS OF GREAT BRITAIN, THE MIDDLE EAST, THE INDIAN STATES AND SOUTH AMERICAN REPUBLICS

F. H. LLOYD & CO. LIMITED

JAMES BRIDGE STEEL WORKS · WEDNESBURY · STAFFS

Phone : DARLASTON 225 (9 lines) Telegrams : STEEL, DARLASTON

SPECIALISTS IN HIGH QUALITY STEEL CASTINGS



THERE IS ALWAYS A BETTER WAY

Heat Treatment Furnaces for Alloy Steel Bars

Fuel . . . . . Towns Gas	Recuperators . . . . . Tubular Metallic
Hearth Dimensions . Length 14′ 0″ Width 5′ 0″	Instruments . . . . Automatic Temperature and Atmosphere Pressure Control
Combustion System . Gibbons-Webb Roof Firing	Load Handling . . . Gibbons-van-Marle 3 Arm Charging Machine

Ask GIBBONS

GIBBONS BROS. LTD. DIBDALE WORKS, DUDLEY, WORCS. Phone DUDLEY 3141 J.T.L.

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Pyromaster

Potentiometer PYROMETER

COMBINES HIGH *Consistency* WITH ROBUSTNESS AND SIMPLICITY

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Bristol's Pyromaster is available as a Recorder —or as a Pneumatically or Electrically operated Recorder-Controller. Send for details.

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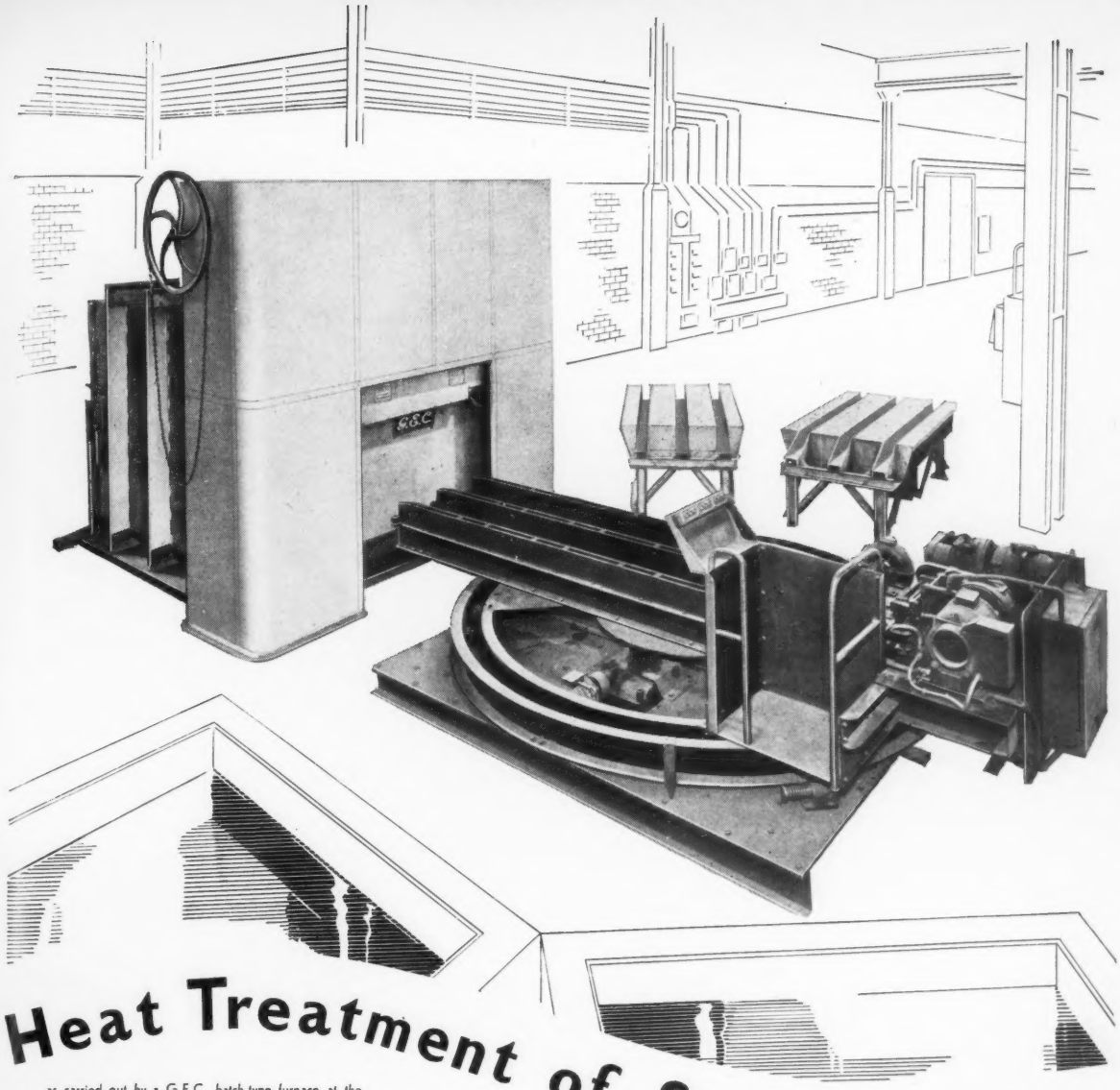

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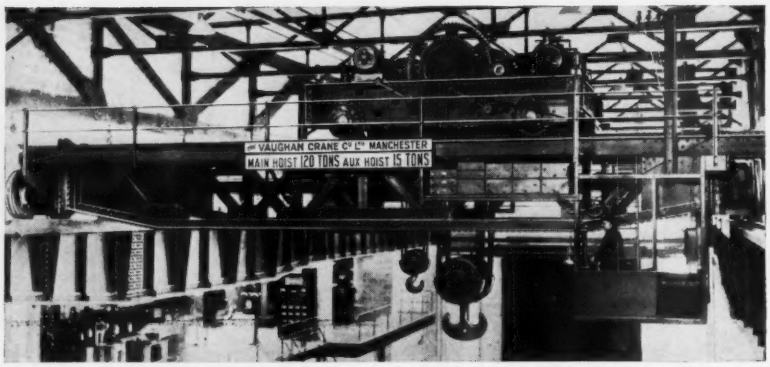

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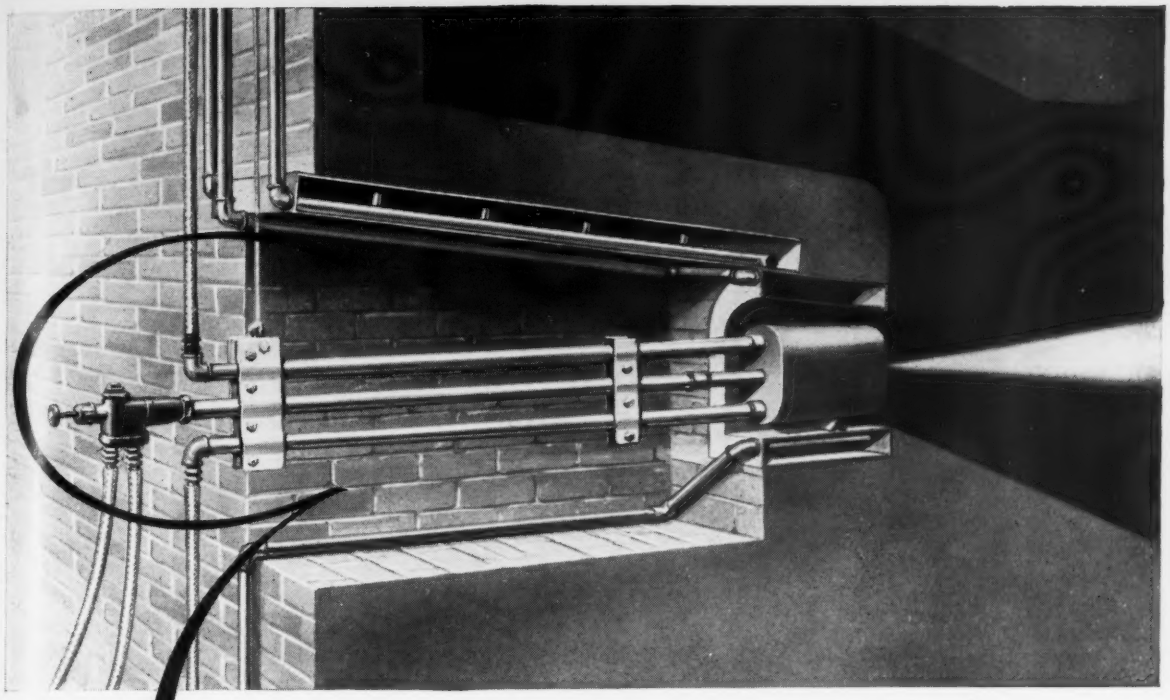

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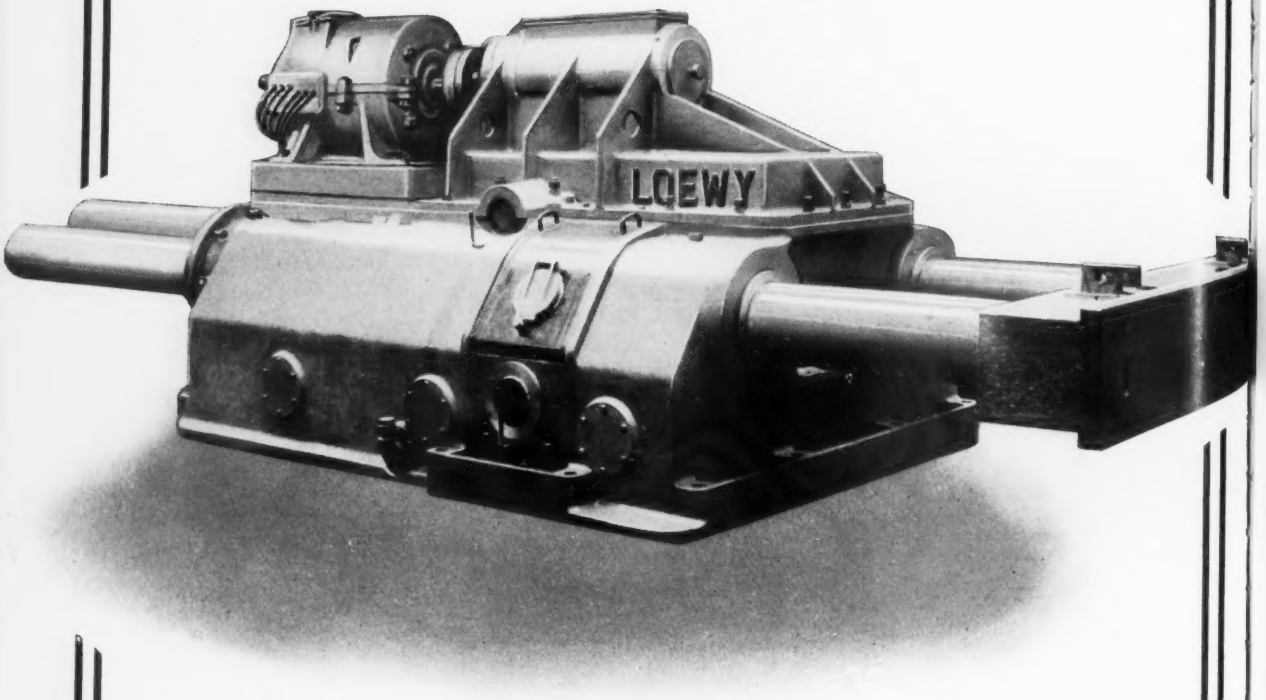

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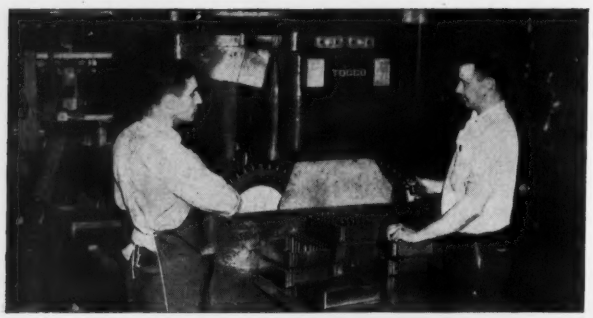

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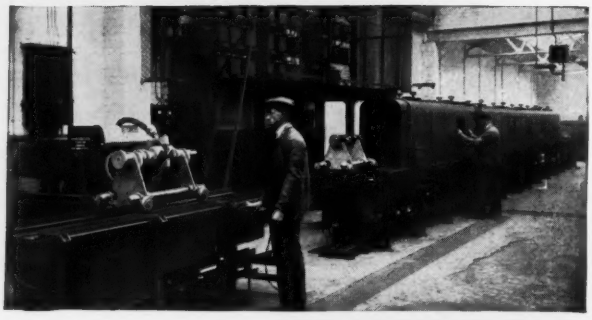

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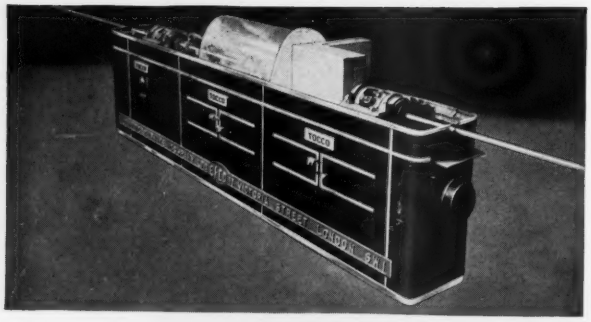

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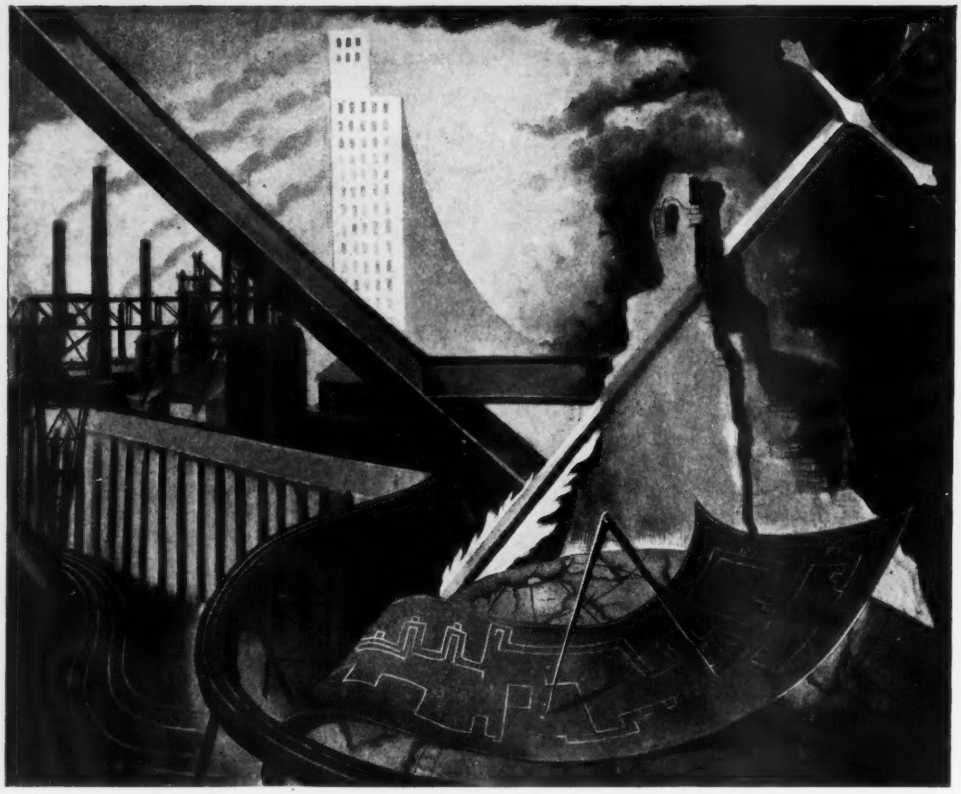

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